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CLEANING THE SEDIMENTATION BASINS AT ST. LOUIS, MO.

Frontispiece.

WATER FILTRATION WORKS.

BY

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Member of the American Society of Civil Engineers.

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PREFACE.

IN 1839 James Simpson built a set of filters for the Chelsea Water Company at London. These filters, the first constructed for the purification of a municipal water-supply, were intended merely to clarify the water, no investigations, at that date, having been made to determine what results, other than clarification, could be obtained by filters properly designed and operated. Twenty-seven years later Mr. James P. Kirkwood visited Europe for the city of St. Louis for the purpose of studying the methods of filtration in use abroad. On his return he submitted a report in which the filtering of the St. Louis water was recommended, following this report in 1869 with a treatise on the "Filtration of River Waters." This book contained the results of his observations and studies of thirteen filter-plants in Europe, and was the first publication to appear in English on the subject of filtration. Able as was this discussion, however, public interest in the question of the purification of polluted waters remained dormant in the United

States until the results of the valuable experimental work conducted at the Lawrence Experiment Station were published in the Annual Reports of the Massachusetts State Board of Health. These reports attracted world-wide attention, cleared up many points that had been but imperfectly understood in the phenomena attending filtration, and gave a stimulus to public interest which has resulted in the establishment of many filter-plants in the United States, as well as in other countries. With the exception of the above-named works, and the authoritative and useful book published in 1895 by Allen Hazen, entitled "The Filtration of Public Water-supplies," the most valuable data bearing upon the subject of filtration are to be found in the not generally accessible reports of special investigations, in the current technical journals in the United States and Europe, and in a few works on the purification of water, which treat the subject principally from the sanitary and chemical points of view. The author has drawn freely upon these sources of information, particularly upon the valuable Annual Reports of the Massachusetts State Board of Health, and the reports on the purification of the Washington, Pittsburgh, Cincinnati, Louisville, and Providence water-supplies. Persons familiar with the reports of the Massachusetts State Board of Health will recognize in the first pages of the chapter on The Theory of Slow Sand-filtration the substance of the very clear statement of the phenomena attending decay and regeneration written by Dr. Thomas M. Drown to whom full acknowledgment is tendered.

Among his professional colleagues who afforded him opportunities of visiting the plants under their direction and also furnished him with many valuable data concerning the construction and operation of filtration works, the author wishes specially to mention the late F. Andreas Meyer, City Engineer of Hamburg; Wm. H. Lindley, Civil Engineer, Frankfort-on-the-Main, Germany; M. Peter, City Engineer, and M. Bertschinger, City Chemist, Zurich; Director Beer and Superintendent Engineer Anklamm, Berlin, and Wm. Anderson, Treasurer and General Manager of the Edinburgh Water-works.

The author is also under obligations to Mr. William Wheeler, Consulting Engineer, Boston, for the photographs of the Ashland, Wis., and Somersworth, N. H., covered filters; to Mr. Geo. I. Bailey, Superintendent Bureau of Water, Albany, for valuable data and for the photographs of the Albany filters; to Mr. Edward Flad, Water Commissioner, St. Louis, Mo., for the pictures of the Intake and Settling Basins of the St. Louis Water-works; to Mr. Morris Knowles, Assistant Engineer in charge of the Testing Station, Philadelphia, for the photographs reproduced in Plates XI, XVI, XVII, XVIII and XIX; and to the New York Continental Jewell Filtration Company for valuable data, and for the illustrations forming Plate XV and Figs. 37 to 45 inclusive.

During the past decade great advances have been made in the development of processes for the purification of polluted waters. These processes, and the works necessary for carrying them out, are described

with sufficient fulness in the following pages to indicate the results that may be attained in the matter of the purification of polluted waters, the means of attaining these results, and the elements entering into the design, as well as into the cost of the necessary works, both as regards construction and operation.

JAMES H. FUERTES.

NEW YORK, *April*, 1901.

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WATER FILTRATION WORKS.

CHAPTER I.

INTRODUCTORY.

WATER AND PUBLIC HEALTH.

Typhoid Fever and Water-supply.—The purity of water depends upon its source and upon the polluting and purifying influences to which it has been subjected. It is now well known that in a community using water polluted with sewage the general health tone gradually falls lower and lower and its death rate increases proportionately. Among the diseases known to be capable of transmission by drinking-water, typhoid fever holds a prominent position. As it is nearly always present in cities, its continued prevalence, in abnormal proportions, indicates excessive pollution, by sewage or fecal matter, of the drinking-water supplied to the community. This is well set forth in Table I, in which the death rates are the averages for several years:

TABLE I.

Kind of Water Used.	City.	Source of Supply.	Typhoid-fever Death Rate, per 100,000 People per Annum.
Pure water	Hague	From sand dunes	4.7
	Munich	Mountain springs	6.0
	Dresden	Ground-water	6.0
	Berlin	Filtered water	7.0
Polluted water	Washington	Potomac R. and wells	71.0
	Louisville	Ohio River	74.0
	Pittsburgh	Allegheny River	84.0

It is also probable that there is a relationship between the annual typhoid-fever death rate in a city and the kind and amount of pollution of its water-supply. This is indicated in Table II, the data for which have been compiled from the records of a great many cities. While the figures are, of course, approximate, there is sufficient reasonableness in the averages to entitle them to consideration.

TABLE II.

Kind of Water Used.	Average Typhoid-fever Death Rate per 100,000 People per Annum.
Pure mountain springs	6
Properly filtered water	12
Pure ground-water	18
Protected impounded supplies	25
Large normal rivers	28
Large lakes	39
Upland streams	44
Polluted supplies	70–300+

Basing calculations on the above averages, it will be seen that, considering the water furnished by mountain springs as the purest obtainable for a city's

supply, and expressing the average annual typhoid-fever death rate of a city using such water by 1 per 100,000 living, the average rate in cities using other kinds of water would be multiples of this in about the following ratios:

TABLE III.

Kind of Water Used by the City.	Comparative Annual Typhoid-fever Death Rate.
Pure mountain springs	1
Properly filtered water	2
Pure ground water	3
Protected impounded supplies	4
Large normal rivers	5
Large lakes	6
Upland streams	7
Polluted supplies	10–30

Thus, for instance, the typhoid-fever death rate in a city supplied with water from upland streams, without large storage reservoirs, would be expected to be about seven times as great as if the water-supply were from pure mountain springs; and the filtration of such water would, on the average, prevent about three fourths of the typhoid-fever deaths.

THE PURIFICATION OF WATER BY NATURAL AGENCIES.

In polluted waters a considerable amount of purification may take place from natural causes. Among these are sedimentation, chemical changes, the action of certain vegetal growths in promoting sterilization,* and the action of certain bacteria to-

* See page 188.

ward liquefying and nitrifying the organic matter present in the water.

Aeration.—The aeration of water, by passing it over cascades, or falls, is popularly supposed to do much toward its purification. The greatest fields of usefulness for this treatment, however, are for the oxidation of iron in solution; the removal of disagreeable gases; the prevention of stagnation, and the retardation of the growth of certain forms of vegetal life in the water, which, by their development, impart disagreeable odors and tastes.

The waters from the deep wells in New Jersey frequently contain iron in sufficiently large quantities to give them a disagreeable taste and to render them unfit for use for many purposes. These troubles may often be removed by simple aeration accompanied by a rapid filtering process to remove the iron salts. Quite extensive plants of this kind are in operation at Atlantic Highlands and Asbury Park. If the iron is present in the form of sulphates, however, simple aeration is not so effective, and a treatment of the water by the addition of milk of lime, followed by aeration and rapid filtration, proves successful. This treatment was resorted to at Reading, Massachusetts.

At Koenigsberg, Germany, the water supplied to the city is allowed to flow about five miles in a natural watercourse to effect the removal of the iron. The iron is deposited on the bottom and the water issues, clear and bright, at the lower end of the open channel.

Generally speaking aeration is ineffective except

for the purposes stated; sometimes it may even have the opposite effect to purification. For instance: In 1897 Professor Albert R. Leeds found that aeration of the Brooklyn water favored the growth of Asterionella, an organism that has caused much trouble, at certain seasons, by imparting a very disagreeable taste and odor to the water. In this case it was found that the multiplication of Asterionella was favored, essentially, by abundant access of light; by a gentle tremulous motion of the water; by the absence of peaty or other coloring matter in the water, and by storage in shallow reservoirs, together with the presence of silica and nitrogenous food matter. So far as was known, the only remedy which proved effectual was the exclusion of light. In order to avoid this trouble, in the case of the Brooklyn water, a by-pass was provided, so that the reservoirs in which Asterionella caused most trouble could be cut out of the distribution system temporarily if necessary.

Effects of Storage.—Ground-waters and filtered waters should generally be stored in dark reservoirs, and should be delivered to the consumers as quickly as possible, as they nearly always deteriorate during storage and upon exposure to light. Surface waters, however, are frequently improved in quality by storage in large, deep reservoirs, particularly if the reservoir sites have been cleared of vegetation and top soil before the reservoirs are filled, and if the feeding streams are somewhat turbid. Under these conditions the polluting matter washed into the reservoirs is greatly dispersed; from 75% to 90% of the sus-

pended matter, together with, often, as much as 80% to 90% of the microscopic vegetal and animal organisms, settles to the bottom and the water is left nearly free from turbidity and objectionable qualities. The absence of decomposing organic matter in the bottom of the reservoir, if stripped, deprives the water of the nitrogenous and carbon compounds necessary to support the life of these microscopic organisms, and, hence, they will not multiply rapidly. Light is necessary to promote the growth of most organisms, but to certain forms it is fatal. Janowski demonstrated that gelatine freshly inoculated with typhoid germs developed colonies in the dark in three days, in diffused daylight in five days, but that in strong sunlight the gelatine became sterile in six hours.

Effects of Mud Deposits.—Deposits of mud in storage reservoirs are not necessarily harmful. In Philadelphia, when the Lehigh basin was emptied in 1886, an analysis of the water covering the mud showed no injurious constituents. The same results were obtained at the Fairmount reservoir, when emptied recently to permit the making of repairs, and also at the Mt. Airy basin, which had not been cleaned for thirty years, and contained from four to five feet of mud.

Plate I shows this reservoir when the mud had been partially removed.

Such deposits in shallow reservoirs may, however, by furnishing proper food, encourage growths of organisms that will by their development impart disagreeable tastes and odors. Mr. George C. Whipple,

Plate I.—Removal of Thirty Years' Accumulations of Mud from Mt. Airy Reservoir, Philadelphia.

Director of the Mt. Prospect Laboratory of the Brooklyn Water-supply, and D. D. Jackson, chemist, have found that such was the case in some of the Brooklyn Reservoirs,* and have recommended, as a remedy, the cleaning of the reservoirs early in the spring and late in the summer.

Effects of the Fouling of Water-mains.—The fouling of the water-mains in Philadelphia, by deposits in them and by growths on their interior surfaces, was considered by some people the cause of the poor quality of the water; and considerable pressure was brought to bear to have the mains cleaned, in order to increase the quantity of water they would deliver and also to improve its quality. The available data concerning the effects of the fouling of water-mains rather strongly indicate that the quality of the water improves in its passage through the distribution pipes. Mr. George C. Whipple found that during the passage of surface waters through pipe lines in Boston there was a considerable reduction in the number of organisms, due to sedimentation, disintegration, decomposition and consumption by other organisms; that there was also a similar decrease in the number of bacteria, except during periods of the year when decomposition was going on in the pipes, and that by their decay the growths tended to produce bad odors and tastes. These rank growths are

* Asterionella; its Biology, its Chemistry, and its Effects on Water-supplies. Geo. C. Whipple and D. D. Jackson, Journal of the New England Water-works, Assn., Vol. XIV, No. 1.

not found in pipes carrying filtered water, or ground-water free from microscopic forms, as such waters do not furnish the necessary food-supply.

Incrustation is generally greatest with clear, bright waters because they contain much oxygen and carbonic acid which, in the absence of mineral matter, are left free to attack the pipes. When pipes become seriously incrusted, so that their capacity is reduced, they may either be cleaned or duplicated. The cleaning of large mains is done with a scraper, a steel tool, which is inserted in the pipe and forced through by the pressure of the water. Pipes smaller than five inches in diameter cannot be readily cleaned in this way unless the pressure is very high. The cleaning is generally done in the night-time, when there is little noise from traffic, as the movement of the scraper in the main must be located by the noise it makes in removing the blisters.

The scraping of small pipes, by hand, is said to cost on the average about one cent per foot per inch of diameter.

The cost of cleaning several large water-mains, including labor, the cost of putting in special manholes for entering the scraper, etc., is given in Table IV.

The danger of using lead pipe with very soft water is well recognized. In such waters there is often enough free acid to attack the lead and thus form poisonous salts. The following case was reported in a recent number of the *Gesundheits-Ingenieur.* Water was brought in a lead pipe to a forester's lodge, at a certain bathing resort in Germany, from a spring

TABLE IV.

Year.	City.	Pipe Lines.		Cost.		Obstruction.	Gain in Delivery, Per cent.
		Diameter, Inches.	Length, Feet.	Total.	Per Foot.		
1877	Oswestry......	6	6,600	$605	$0.021	Large stones, lead, and defective pipe.	54.4
		7	23,100				
1878	Lancaster......	8	9,780	150	.015	Peaty matter.	56.1
1880	Durham........	12	7,038	455	.064	Lead, spade, handspike, and wagon-bolt	
1880	Bradford	18	24,420	3170	.13	Stones, lead, crowbar, etc.	55.16
1881	Halifax, N. S...	12	6,999	455	.065		
	" " ...	24	160,800	167.30	.001		
1882	" " ...	20	26,848	36.67	.0014		
to	" " ...	15	348,568	204.44	.0007		
1898	" " ...	12	33,316	793.01	.024		
	" " ...	16	20,514	1074.42	.05		
1882	Exeter.........	10	10,560				
1882	"	12	10,560	960	.04		
1883	"	13	13,728				
1885	White Haven...	11	19,536	2580	.13	Mussels, stones, and lead.	27.6
1885	Bristol.........	6	7,635	175	.02	Stones.	
1886	Denbigh.......	6	7,920	750	.095	Stones and lead.	
1887	Omagh........	6	7,656	265	.035	Lead and defective castings.	300.0
1887	Halifax........	6	2,328	105	.045		
1888	Ulverston......	6	5,280	360	.069		
1890	Dundee........	15	10,560	1280	.12	Wood and stones.	
1890	Dumfries......	9	5,280				
1890	"	8	21,120	565	.026		
1890	Scarborough...	8	6,600	310	.047	Stones.	
1891	Newport.......	10	3,240	250	.075	Lead.	
1891	Lanark........	7	31,680	375	.012	Lead, wood, and stones.	33.7
1891	Guisborough...	6	5,280	180	.034		

about two hundred feet distant. On investigation it was shown that the plumber, when soldering the joints, had allowed a lot of lead filings to remain in the pipe. The daughter of the forester became ill some days after the completion of the work, the illness proving fatal shortly afterward. A post-mortem examination demonstrated the presence of lead in several of the organs of her body, and the water, which was very pure at the spring, was found to contain 0.95 mg. of dissolved lead per litre.

Self-purification of Streams.—It is popularly believed that running water, after a few miles of flow, will purify itself to a high degree. As a matter of fact the amount of purification that takes place, naturally, in a running stream is quite limited, so far as the disappearance of the disease germs is concerned. Their dispersion through the mass of the water, and the greater dilution caused by the increasing volume of flow, are probably the greatest factors in the apparent lessening of pollution toward the mouths of rivers.

Some of the influences tending toward self-purification are referred to on page 188.

Effects of Freezing.—Freezing will not purify or render safe for use water which has previously been polluted with fecal matter. Ordinarily it has been observed that clear, transparent ice, when melted, yields about ten per cent. as many bacteria as were present in the raw water; or, in other words, the percentage of removal of the organisms would be comparable to that obtained by sedimentation in large reservoirs.

THE PROTECTION OF WATER-SUPPLIES.

Permissible Pollution.—There are certain conditions under which the pollution of a stream is permissible. This right is recognized in various States by the Mill Acts, which are intended to foster the development of industries. These acts could not be operative unless the right of stream-pollution were conceded, to a certain extent. The right to prevent the discharge of sewage into a river, when it would result in a public nuisance, is now well established. The Supreme Court of Connecticut has recently restrained the cities of Danbury, Waterbury, and New Britain from discharging their sewage into the Still River, Naugatuck River, and Pipers Brook, respectively, because of the creation of nuisances. Similar decisions have been made in other States. In many cases these decisions prepare the way for the collection of damages, the cities, or parties causing the nuisances, finding it sometimes more convenient to pay the damages annually than to put in the costly works necessary to correct the evils.

Legal Protection of Water-supplies.—The law under which New York City maintains the purity of its water-supply gives the city power to obtain title to all lands in the Croton watershed necessary for the construction of dams, reservoirs and appurtenances, and also the power to secure title to strips of land around the edges of these reservoirs, and the banks of the streams feeding them, to insure the sanitary pro-

tection of the water. A further act, passed in 1893, gives the city power to acquire the title to any real estate "for the sanitary protection of all rivers and other watercourses, lakes, ponds and reservoirs in the counties of Westchester, Dutchess and Putnam, so far as the same now are, or hereafter may be, used for the supply of water for the City of New York." Unfortunately, as the laws now stand, New York City is unable to go to other water sources for an additional supply, but active measures are being taken to remedy this fault so that this great Metropolitan District may have powers similar to those granted to other cities of the State.

In 1898 a law was passed which gives any town in New York State the privilege of purchasing the property and franchise of its water-works, at any time the company may be willing to sell, at a price to be agreed upon, the city being empowered to bond itself to pay for the works, and also to assume their indebtedness and to operate them.

Provisions for Betterment of Water-supplies.—While all these laws regarding the protection of water-supplies have been drawn up with a view of throwing safeguards around the public health, the time has come when we are forced to realize that legal enactments of this kind are inadequate, and that the way must be prepared to permit the citizens of any city or town to secure water as pure as it is possible to make it. It is also true that legislation tending toward that end must be secured through the exercise of great discretion and wisdom; any actions that would disturb con-

fidence in investments, affect the market values of stocks and bonds, or raise questions as to the ability of concerns already in operation to pay fixed charges and customary dividends, would be met with determined opposition.

Requirements of Water Companies in the Matter of Protection.—The laws of to-day require a water company to exercise only ordinary and reasonable care in the protection of its water; and it has been, thus far, impossible to fasten upon a company or corporation the responsibility for the deaths of persons resulting from the drinking of such water. It is not difficult to see why this should be so. In order that the company might be forced to pay damages it would have to be shown, among other things, that there was an intent to defraud or deceive; that there had been criminal negligence in the care of the supply; that the water was unquestionably the cause of the illness or death in question, and that there had not been contributory negligence on the part of the user. When the pollution of the water is a matter of common knowledge, fully discussed in public and in the press, and when the deceased had knowledge of the pollution, it has been held that drinking of the water was contributory negligence. If the pollution were of an accidental nature the difficulty would lie in proving that the water was the cause of the trouble in that specific case, as there are many well-known agents, other than water, by means of which disease may be spread.

Protection of Surface Supplies.—Generally speaking,

only those supplies derived from surface gathering grounds, small rivers, and, to a certain extent, those from ground-water, can be protected by legislative or administrative action. As regards protection, large rivers are in a different class from small streams. Some sanitarians hold that the upland streams should be regarded as the water-supply sources of a land, and the large streams as its sewers, recommending legislative action to govern the protection of the small streams and to determine the degree of permissible pollution of the large ones. There are many difficulties in the way of securing uniform legislation on this question, because of the great diversity of interests affected, and the difficulty of drawing the line between large and small rivers. The question must be specially solved for each locality by the adoption of that plan which will be of most benefit to all interests. On a very large river, for instance, it would be far cheaper, and would afford greater security to the people, for all the cities to discharge their sewage into the river unpurified, and then purify the drinking-water drawn from it, than for them to purify their sewage and then drink the untreated river water. Under some conditions it might be necessary to purify both the sewage and drinking-water.

The topographical conditions on small highland streams are not generally favorable for the development of large industries, and it is possible, therefore, on such, to enforce restrictions against pollution because on the small streams the conflicts of interests are not so great as on the large lowland rivers.

Ownership vs. Legal Protection.—Absolute ownership of the watershed is, by some, considered more effective than its protection by legal enactments. Manchester and Liverpool own the watersheds from which their water is derived, and recently Mr. James Mansergh, President of the Institution of Civil Engineers, has recommended to Birmingham the purchase of the 45,000 acres of land from which its water-supply is drawn. Edinburgh and Glasgow, however, protect their watersheds by legal enactments and by contracts with the landowners. In this country the water companies generally own only the land upon which the reservoirs and buildings are situated, obtaining easements for right of way for pipe lines, etc., and in some of the States depend upon the legal powers conferred upon the Board of Health to prevent the pollution of the water. In some cases these powers are quite ample, while in others they are practically inoperative. It is not yet clearly established that ownership of the watershed permits of greater protection of the water-supply than can be obtained by legal enactments without such ownership. Judging by their typhoid-fever death rates, Manchester and Liverpool, owning their watersheds, do not seem to be more effectively protected against typhoid fever than Brooklyn, New York, Glasgow or Boston, having control over their supplies mainly by legal powers.

Effects of Surface Washings.—It is becoming pretty well recognized that surface washings are an important factor in the pollution of water-supplies. It is

quite interesting, in this connection, to note that the annual typhoid-fever death rates of New York, Boston, Cleveland, Detroit, Columbus, Louisville, Paterson, Pittsburgh, San Francisco, and Toledo have, at various times, fluctuated synchronously for a number of years with the annual rainfall for the corresponding years; indicating that the typhoid fever in these cases was proportional to the amount of polluting matter washed into their respective sources of supply.

The available evidence goes to show that legal protection of a water-supply may effect a considerable reduction in the death rate of a city, but that such protection cannot guarantee a water as pure as spring-water or properly filtered water. The logical deduction is, therefore, that in most cases filtration of the water will be required where there is danger of sewage-pollution. Of course, as a matter of precaution, all safeguards should be put in force in such matters, and the direct sewage-pollution of a body of water, intended for use as a source of supply, should, if possible, always be prohibited, whether or not filtration is subsequently employed. It is also well established that the purification of the sewage of cities, before discharging it into a stream subsequently used as a source of supply, will be less effective as a health preservative measure and less feasible from a financial point of view than the purification of the drinking-water supplies drawn therefrom. Undoubtedly there will be many situations where both processes will be necessary.

It has been the author's firm conviction for some years that the time is not far distant when the public will demand the purification of all supplies derived from surface gathering-grounds, when practicable. A similar view was expressed in the report of the Mayor's Expert Water Commission,* of Philadelphia, in reporting upon the Filtration of the Philadelphia Supply.

The available statistics indicate that surface-water supplies, except those which have enormous storage reservoirs, cannot be generally regarded as safe. Large reservoirs afford considerable protection to surface-water supplies. The great capacity of the reservoirs permits the impurities washed into them to be thoroughly dispersed, favors the sedimentation of a large percentage of the bacteria, and furnishes favorable conditions for the oxidation and absorption of the nitrogenous matter in the water by aquatic plants and microscopic life.

Large surface supplies are generally more difficult to protect than small ones. The actual protective measures are naturally divided into two classes: those which must be used when the works are building, and those which must be enforced after the works are placed in operation. When a supply of surface-water is to be furnished, it is first necessary to acquire the land upon which the reservoirs will be situated. In large works this will require the acquisition of many

* Report on the Extension and Improvement of the Water-supply of the City of Philadelphia, by Rudolph Hering, Joseph M. Wilson, Samuel M. Gray.

farms, and perhaps villages and towns, and the destruction of many industries. The land taken should include everything lower than high-water line of the proposed reservoir, with an allowance of two or three feet for exigencies; in addition, a strip, 200 or 300 feet wide, should be secured all around the water, to give perfect control over the shores. The same policy should be followed, if possible, in regard to the principal feeders of the reservoirs. This property is secured usually by appraisal by commissioners, and in many cases it results in a direct benefit to the inhabitants of the territory taken.

After the site has been acquired, the fences and buildings must be removed to other sites, or burned, and the vegetation must be cut down and burned, or removed. The necessity of removing the top soil and small vegetation has in late years been given much prominence. Some of the older Boston reservoirs were not so treated, and the great deterioration of the water due to the slowly decomposing organic matter was a source of much anxiety. This trouble has been remedied at great expense by drawing down the water, pulling out the stumps, removing the soil, in some cases to great depths, and paving the slopes. Late investigations have shown that the removal of from 6 to 12 inches of the top soil will accomplish all that can be desired, and the covering of the mucky places with a foot of gravel has served as well as removing the entire deposit. It is also necessary that the bottom of the reservoir should be graded so that all the water will drain to the outlet, and not

leave stagnant, isolated pools when the water is drawn down. In addition to the treatment of the reservoir site, it is necessary to drain, or cut off, the swampy areas on the watershed by ditches or banks. Sometimes a few ditches satisfy the conditions, and sometimes it is necessary to convey the water feeding the swamp in direct channels to a near-by watercourse, and isolate the swamp by embankments. While all these operations are going on, and while the dams and accessory works are building, tight portable earth-closets must be provided for the use of the workmen and every precaution must be taken to insist upon their proper use and care, there being several cases on record where epidemics have resulted from the neglect of this simple precaution.

During the operation of the works the principal sources of pollution that must be controlled are the washings from the streets and roads; the washings from the fields; the pollution from swamps and bogs; the refuse from manufacturing establishments; sewage matter; garbage; farm refuse, and the drainage from cemeteries.

Much of the pollution from the street-washings, in the villages, can be abated by efficient street-cleaning methods and sanitary regulations regarding the collection and disposal of the refuse. Street-sweepings have a value and can readily be disposed of to farmers, in the neighborhood, for fertilizing purposes. The washings from rural roads can nearly always be purified, to a certain extent, by diverting the ditch-

water at intervals over lands adjoining the road, whereby, through sedimentation, straining and partial filtration, a large amount of the objectionable impurities may be removed. The washings from cultivated lands, when the fertilizer is of an objectionable character, should be spread out over grass land, or passed through a porous soil, for a considerable distance, before being allowed to flow into the feeders of the supply.

Protection from Sewage-pollution.—The problem of dealing with the sewage of the villages resolves itself generally either into a system of dry removal, or into a system of water carriage, followed by purification, before allowing it to flow into the feeders of the supply.

The most convenient method for dry removal is to provide the closets with coverable pails or boxes, into which dry earth or ashes may be thrown, as an absorbent. This method has been in use at Hemlock Lake, N. Y., the source of the domestic supply of Rochester, since 1885, and has proven satisfactory. It has the advantage that the matter deposited in the receptacles can be kept from direct contact with the air, and hence, also, away from flies. Pail contents, garbage, and other decomposable matter should be buried in a safe place, or burned in refuse destructors. Human fæces should not be exposed on the surface of the ground near a water-supply source nor used for fertilizing the soil.

The principal disadvantages of the pail system when applied to cities are the great cost and inconvenience

of the method as compared with the water-carriage system followed by the purification of the sewage.

The State Boards of Health generally enact laws to prevent the discharge of sewage from cities into the water-supply sources of other cities, and therefore, upon proper complaint, such nuisances may be abated. Boston, as is well known, encourages the towns and cities within the shed of her water-supply to take their sewage outside the limits, if possible, or to put in satisfactory plants for purification of the same, paying fifty per cent. of the cost of the work, the towns paying the other fifty per cent. The greatest difficulty is generally in enforcing the law, as this can only be done by proper legal processes, entailing often considerable delays.

Protection of Lake Supplies.—The protection of supplies derived from large lakes is hampered by many difficulties, and the protective measures must depend upon the direction of the surface and submerged currents, the size and growth of the city, the relative locations of the outlets of sewers, drains and large polluted streams, the amount and direction of the lake traffic, the depth of the water, annual rainfall, and many other factors. An interesting case of the pollution of a lake supply has been reported by Professor Gardiner S. Williams, formerly Engineer of the Board of Water Commissioners of Detroit, Mich. The sewage of Port Huron is discharged into the Black River, a sluggish stream emptying into Lake St. Clair, 60 miles above Detroit. In 1891 the Government commenced dredging operations in the Black River to

improve navigation, and the mud taken from the bottom was dumped into the St. Clair River, about 60 miles above the intake of the Detroit water-works, which are just below Lake St. Clair. Fifty days after the dumping of the first scow-load of polluting material from the Port Huron sewers into the St. Clair River, there were four deaths from typhoid fever in Detroit. This would allow ten days for the water to flow from Port Huron to the intakes, fourteen days for the disease to incubate, and about twenty-six days for the disease to run its course. Many cases followed these four, the disease disappearing some weeks after dredging operations were suspended. The next year typhoid appeared again after the dredging had begun; and again it disappeared when dredging was stopped.

These conditions have followed one another since that time, and investigations have shown that they prevailed in previous years. As far back as 1886 it was found that typhoid fever appeared in Detroit during those years when dredging operations disturbed the bottom of the St. Clair River or Lake St. Clair, above the intake of the water-works.

All lake cities, as they grow to larger proportions, find it necessary to gradually extend their intakes further from the shores, unless the purification of the water is determined upon. At the city of Chicago the intake has been pushed out successively from 700 feet to two miles and then to four miles. Cleveland has now under construction a new intake tunnel which will be 26,000 feet long, when completed; and the intake for the city of Buffalo has been extended from

330 feet to 1,020 feet. In Zurich, Switzerland, instead of extending the intake further from the shore to get pure water, a large plant has been constructed for filtering the entire supply from the lake.

THE PURIFICATION OF WATER BY FILTRATION.

In the following pages the works and operations necessary for the purification of drinking-water for cities and towns and large institutions, by filtration, will be described with some fulness. The science of water-purification is still in process of development. Each new experimental plant brings to light new difficulties and new methods of overcoming them. Experimental work, such as that done at Louisville, Cincinnati, Pittsburg, Providence, and Philadelphia, and now under way at New Orleans, is of incalculable value, as it leads to the discovery of the proper treatment for the purification of waters of different kinds. Processes that are applicable for the treatment of clear polluted waters fail entirely with turbid waters; and turbid waters themselves vary so greatly in regard to character and seasonal distribution of sediment that each case requires a special study. Some clear waters, also, on account of rank algæ growths, at certain seasons, must have special treatment before they can be filtered successfully.

The filters described at length in this work are classified under two heads—slow sand-filters and rapid sand-filters. These terms must be used in the restricted sense; both refer to filters in which the

filtering medium is sand. The slow sand-filters may be, though they generally are not, operated with the aid of chemicals for producing the surface film, while the rapid sand-filters can only be efficient by using a coagulant, such as aluminum hydrate, to form the film artificially and rapidly.

Other types, such as the Fischer or Worms filter, using slabs of concrete, and the Pasteur-Chamberland, using tubes of unglazed porcelain, belong in a different class.

There are also slow sand-filters operated in connection with a coagulant; such as the filters at Antwerp, where the coagulant is ferric hydrate, produced by the Anderson process, and the experimental filters tested at Cincinnati by Mr. Fuller, and called by him "Modified English Filters." There is also the process used in the Maignen system, in which a layer of asbestos forms the surface film over the sand.

The indications are that the development of some preliminary process for straining out the finely divided particles of clay, by the use of prepared sponges, layers of cloth, or other absorbent materials, instead of using a coagulant, may, in the future, play an important part in water-purification.

As a rule, most waters which would be used for a water-supply require the same cycle of operations to render them fit for use as drinking-water; that is, the removal of turbidity, color, and pathogenic bacteria. These operations usually require works for removing the suspended matter by sedimentation, with or without the coagulation of the finer particles; the removal

of color and pathogenic bacteria by filters, with or without the aid of coagulation, and the storage of the filtered water in sufficient quantities to permit the filters to operate at a nearly uniform speed, although the draft on the works may vary considerably in rate at different times of the day. These different works will therefore be discussed in the subsequent pages in the following order:

Intakes.

Sedimentation.

Settling basins.

The purification of water by slow sand-filtration.

The design, construction and operation of slow sand-filters.

The purification of water by rapid sand-filtration.

The construction and operation of rapid sand-filters.

Other methods of filtration.

Filtered-water reservoirs.

CHAPTER II.

INTAKES, SEDIMENTATION, AND SETTLING BASINS.

INTAKES.

Flowing waters may be divided into two general classes: those in which tidal influences may cause a reversal of current, or at least a checking of velocity, and those in which the flow is continuous in one direction.

Tidal Streams.—Water-supplies taken from streams subjected to tidal reversals of current are usually also sewage-polluted, and, therefore, in the location of the intake due regard must be had to the time of collection of the water to insure that it may be taken only when it is at its best. The intake for the Antwerp works is at Waelhem, a small village about eight miles to the south, on the banks of the River Nethe. About two miles above Waelhem the Nethe is joined by two streams, the Seine, upon which Brussels is situated, and the Dyle, flowing through Malmes. Below the junction the river is called the Rupel; this flows into the Scheldt, upon which Antwerp is situated. The range of tide at Waelhem is about 13 feet 6 inches. In order to avoid taking in the polluted waters of the

Rupel, as they flow past Waelhem, on the flood tide, and the waters of the Nethe, contaminated at low water with the sewage of the towns situated above the intake, the water is let into the settling basins three hours after high water. The bottom of the intake is .33 foot above low tide. Water taken under these conditions and purified by ordinary sand-filtration was pronounced by the authorities sufficiently good for the supply of the city. At Shanghai the water is taken from the River Huang Poo, a branch of the great Yang-tse-Kiang. The range of the spring tides is from 8 to 9 feet. The intake for the water-works is located below the city of Shanghai, where the great dilution from the Yang-tse-Kiang, on flood tide, and the wide section of the river, make the danger from pollution less than if the intake were above the city, where the river section is very much smaller. The valves of the intakes are placed two feet above the low-water level, so that no water can enter them until fully one hour after flood tide has set in. By this means the sewage of the city and its suburbs is washed into the upper reaches of the river during the time the water is being taken into the settling basins. Whatever sewage matter may have gone down the river on the previous tide is so greatly dispersed in the waters of the Yang-tse-Kiang that it is hardly detectable.

Rivers with Stable Banks above Flood Height, and with small Range of Fluctuation of Level.—If a river has stable banks, at a slight elevation above high water, a fair velocity, with a small range of fluctuation of surface elevation, the intake should be constructed

with the bottom low enough to collect the water at all times, and should consist of one or more pipes or conduits ending in a chamber at the face of the bank. The distribution of sediment in rivers, both in the vertical and horizontal, is discussed on pages 35 and 36. Movable duplicate screens in the chamber will prevent the entrance of floating and other objects that might interfere with the valves of the pumps. At Berlin, at the Mueggle See works, on account of the shallow water and sloping bottom, the water near the shore is generally muddy from the action of the waves. To secure clearer water the bottom of the lake was dredged to a depth of 6.6 feet in front of the works, for a distance of about 400 feet from the shore to the point where the bottom drops off rapidly to a depth of about 26 feet. The intakes are box conduits, with a sectional area of about 24 square feet each, built up of oak planks, and extending from the deep water to the screen wells or shafts at the shore.

Rivers with Stable Banks below Flood Height.—If the river has stable banks, which are below flood height, and the works are protected by levees and dikes, the intake may still be as above described, but it will then be necessary to provide a gate in the conduit, placed in a manhole located in the dike, in order to regulate the amount of water admitted to the works when the river is very high, as was done at Hamburg. If the gate were located behind the dike the hydrostatic pressure on the inside of the conduit might cause its rupture if it were of masonry construction.

If the settling basins are lower than the river, in ad-

PLATE II.—INTAKE OF THE ST. LOUIS, MO., WATER WORKS.

dition to the gate in the conduit in the dike, referred to above, it may sometimes be necessary to provide a reflex gate or valve to prevent the water from escaping to the river, in case the attendants should neglect to close the gate when the basins were filled. If the basins are to be arranged to be flooded quickly when the water is at its best, a relief pipe must be built to provide means for the escape of the air contained in the conduit, thus avoiding the dangers incident to concussion, as was done at Antwerp.

Rivers with Shifting Banks and Bottoms, and Great Fluctuation of Level.—When the river has shifting banks and bottom, and the range of fluctuation of surface level is great, intakes become very expensive structures. The intake, in this case, must start from a point in the bed of the stream where the channel is permanent, and should consist of a masonry or other heavy structure, resting on a firm foundation, and constructed with a view of resisting the action of the water, ice and floating objects. Under these conditions pumping must always be resorted to between the river and the settling basins. The conduit from the intake to the pump-well must pass under the bed of the river, and may be enlarged, before reaching the pumps, to form the screening chamber. The intake at the St. Louis water-works is of this type.

SEDIMENTATION.

Amount, Character and Distribution of Sediment.—The purification of polluted water may require the

removal therefrom of suspended particles of finite dimensions, matters in solution, and microscopic objects, both animate and inanimate. For the removal of the first class of matter, straining, or sedimentation alone, or combinations of these methods, will generally suffice; for the second and third classes, chemical or mechanical treatment, or some method of filtration, will probably be necessary.

Waters taken from large lowland rivers flowing through valleys or plains, formed of the detritus and washings of the highlands, carry, at all seasons, large quantities of matter in suspension. A certain part of this matter can be removed by allowing the water to stand in comparative quiescence in large settling basins or reservoirs. The amount of matter that can be carried in suspension depends on the viscoscity of the water; the chemical composition and degree of comminution of the matter in suspension; the eddies caused by the deflection of the strata of water by impingement against the bottom and sides of the stream; vortex motion, and probably on other imperfectly understood causes. It will be seen therefore that a river may carry different amounts of matter in suspension at different periods of the year, and at different portions of its course. This is well illustrated in the case of the Mississippi River and its tributaries, the estimated average turbidity in parts per million of the Allegheny at Pittsburgh being given as 50; the Ohio at Cincinnati as 230; the Ohio at Louisville as 350, and the Mississippi at New Orleans as 560. The average estimated turbidity of the Merri-

mac at Lawrence is given as 10; of the Hudson at Albany as 15 and the Potomac at Washington as 80 parts per million respectively.* The quantity of sediment carried in flowing waters is discussed more at length on pp. 64 *et seq.* In large rivers, flowing through lowlands, it has been frequently observed that the amount of suspended matter gradually decreases, per unit of volume of water, toward the embouchure, though this may not always be the case. It has also been observed that the weight of sediment per unit of volume of water does not always increase with the velocity of the river, nor with the volume of flow, but that a greater load is often carried per unit of volume in dry-weather flows than during floods. In turbid flowing water, that near the surface contains the least suspended matter per unit of volume of water. It is also apt to be more free from bacteria, both on account of the influence of sunlight, and from their being carried down by sediment. That the amount of sediment is less at the surface than at other depths is shown by numerous recorded observations. It is perfectly shown by the determinations for the Garonne,† and also in the data compiled by Elon H. Hooker, Ph.D., C.E.‡

Such few measurements as have been made throw no light on the question as to whether more sediment

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* Report to Hon. James McMillan, Chairman Senate Com. on the Dist. of Columbia, Washington, D. C., by Rudolph Hering, George W. Fuller, and Allen Hazen.

† Notice sur le Port de Bordeaux, M. R. de Volontat, Paris, 1886.

‡ Trans. Am. Soc. C. E., vol. XXII. p. 414.

is to be expected in the centre of the stream than near the banks.* So far as our present knowledge goes there seems to be but little difference.

There is a certain degree of comminution, for any given material, at which the rate of sedimentation of its particles in quiet water would be so slow as to be practically zero. This partly explains why water which contains very finely divided sediment clears slowly, and also why, after a certain period of time, practically the same amount of clarification will exist from the top to the bottom of the water. This occurs in the case of the water of the Mississippi at St. Louis. There it has been found that water can be drawn off from the settling basins at the thirteen-foot level with the same benefits, as to clarification, as could be had by drawing it off from the top.

Turbidity. Standard of Measurement.—The method devised by Mr. Hazen for the measurement of turbidity is based on the depth, in inches, that a platinum wire 1 mm. in diameter and 1 inch long can be seen when submerged below the surface, the results being expressed in the reciprocals of these depths. Thus, at a depth of 1 inch the turbidity is 1, at 4 inches it is .25 and at 40 inches .025, etc. The limit of permissible turbidity is variously estimated at from .2 to .025, as water of this degree of clearness will show no color to the ordinary observer when seen through a glass. The permissible limit, however, must depend largely on the people who use the water, and turbidity much higher than

* Report on the Mississippi. Humphreys & Abbott, 1861.

this, occurring only occasionally, might not cause unfavorable comment.

Another means of indicating the turbidity of a water is to state the parts per million of suspended matter contained therein. This method was adopted by Mr. Fuller in his Louisville and Cincinnati experiments. Mr. Geo. C. Whipple, Director of the Mt. Prospect Laboratory, Brooklyn, uses silica standards,* prepared from diatomaceous earth and distilled water for estimating turbidity. Tubes are filled with the mixture diluted by known quantities of distilled water, and the sample under observation is compared with the various standards to determine its turbidity.

Rate of Sedimentation.—The rate at which clarification takes place in a quiescent turbid water varies according to many different causes. In 1865 Mr. Flad found, from experiments with water taken from the Mississippi at St. Louis,† that of a total of 1,000 parts in suspension, 944.5 parts settled during the first 24 hours, 22.35 parts during the second 24 hours, 2.92 parts during the second 48 hours, while 30.23 parts were still in suspension after 96 hours.

Water taken from the Garonne often shows turbidity after eight days, and muddy water taken from the lower Elbe shows very slight sedimentation until after the lapse of 24 hours. The water of the Missouri,

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* Silica Standards for the Determination of Turbidity in Water. Geo. C. Whipple and Daniel D. Jackson. Technology Quarterly, Dec., 1899.

† Silt Movement in the Mississippi. R. E. McMath, *Van Nostrand's Mag.*, 1883.

at Omaha, often refuses to settle in a period of 72 hours, while the waters of the Delaware and Schuyl-

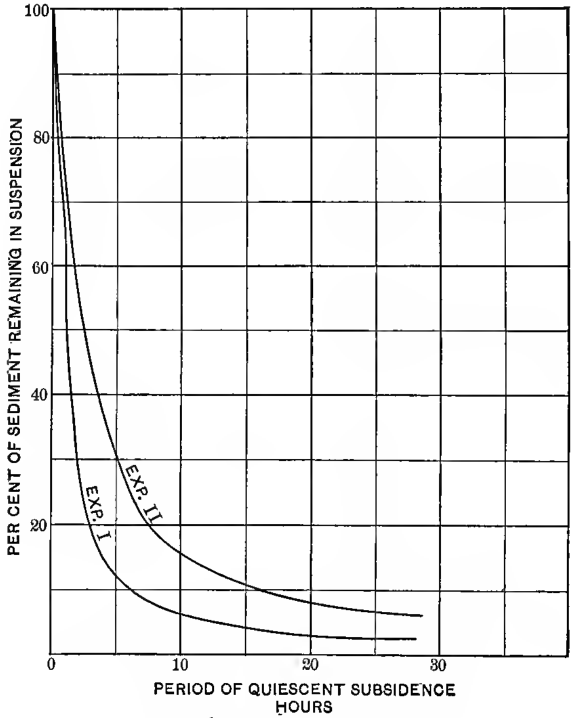

FIG. I.—RATE OF SUBSIDENCE OF MISSISSIPPI RIVER WATER AT ST. LOUIS, MO.

kill Rivers, at Philadelphia, sometimes show more matter deposited in a given sample of water at the end of 24 hours than in the same sample after the lapse of 48 hours.

The rate of clarification of the Mississippi River water, as determined by the experiments of Mr. Flad,

n 1886, is shown in Fig 1, on page 38. The curves epresent the rate of deposition of sediment in differ-nt periods of time for two sets of experiments. It vill be observed that the amount of sedimentation vhich took place after the first 24 hours was very in-ignificant. The water in experiment II cleared more lowly than in experiment I, indicating a more finely omminuted sediment.

At Cincinnati* the Ohio River contains, at times, a sediment so finely divided that only 75 per cent. of t, on the average, can be deposited in three days by simple subsidence. The relative estimated range of removal of suspended matters, in different periods of ime, are given as follows:

TABLE V.

Period of Subsidence.	Percentage Removal of Suspended Matter.		
	Maximum.	Minimum.	Average.
4 hours................	85	25	62
8 "	90	30	68
2 "	95	40	72
6 "	95	45	76

Effects of Winds.—Experiments made at St. Louis, o show the relative rates of subsidence of the water n the settling basins open to the weather, and in a stand-pipe protected from the wind, demonstrated hat there was no practical difference between the

* Purification of the Ohio River Water, for the Improved Water-supply of the City of Cincinnati, O., 1899.

two. The samples from the stand-pipe were taken six feet below the surface, and those from the settling basins were taken from the surface of the water. On the strength of these indications it was decided not to cover any settling basins needed in future extensions of the works.

Effect of Temperature.—The influence of temperature on the rate of sedimentation has been found to be undoubted and positive; sedimentation taking place more rapidly in warm* than in cold water.† A difference in temperature of a few degrees in the water in different parts of the settling basin may act as a disturbing element to prevent sedimentation by setting up convection currents due to differences in density. At St. Louis, in the Chain of Rocks settling basins, vortex motion has been observed four days after filling has been stopped.‡

Effect of Light.—Light is also a factor in the rate of sedimentation, though its effects may be too slight to entitle it to mention. Mr. Andrew Brown, in experiments with phials filled with turbid water, found that there was a tendency toward more rapid settling in those protected from light than in those not so protected. Not enough is yet known about this subject, however, to enable us to say whether the phenomena should influence in any way the designing of settling basins.

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* Subsidence of Fine Solid Particles in Liquids: Carl Barus, Bulletin No. 36 U. S. Geological Survey, 1886.

† Mass. State Board of Health, 1895, H. W. Clark.

‡ Sedimentation. James A. Seddon, *Eng. News*, Dec., 28, 1889.

Use of Chemicals to Aid Sedimentation.—The use of chemicals for hastening sedimentation may sometimes be advisable if the water contains in suspension particles of argillaceous, silicious or earthy matter, so finely divided that their removal cannot be accomplished by simple sedimentation.

Such a plan has been recommended for Cincinnati, where it will be most advantageous to introduce the sulphate of alumina into the water as it enters the settling basins, securing in a few hours as much clarification as could be had by several days of simple subsidence. A similar practice has been recently recommended for the City of Washington, D. C.* At Sandhurst, Victoria, Australia, the water from surface gathering grounds contained as much as from 24 to 32 grains of yellowish-brown clayey matter per gallon, and filters were not able to remove it. The addition of 5.6 grains of lime per gallon gave a clear water after 10 hours of settlement.

Results of Sedimentation.—As a general thing, practically all the suspended matter which can be economically removed by simple subsidence will be precipitated in 24 hours, although in some cases longer settlement may be more economical than coagulation and secondary subsidence. Frequently when certain waters stand in reservoirs exposed to the bright sunlight, they develop very disagreeable odors and tastes, the removal of which requires a further purifying treatment. Such troubles add considerably to

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* Purification of the Washington Water-supply, Senate Report 2380, 56th Cong., 2d session.

the expense of purification, necessitating, in some cases, thorough aeration; in others filtration and aeration, and in others some chemical or mechanical treatment to remove the objectionable qualities. Too great a storage capacity, therefore, may sometimes prove a source of expense, and in such cases it may be found cheaper to remove only a part of the suspended matter by means of settling basins, and to depend upon coagulation and secondary subsidence, or upon filters operated at a comparatively high rate, with a coagulant, for the removal of the remainder.

The results that usually may be expected, toward effecting purification by sedimentation, are the removal under poor conditions of from 25 to 50 per cent., and under favorable conditions of from 90 to 99 per cent. of the suspended matter by weight. With the deposition of the sediment, there will also take place, to a considerable extent, a subsidence of some of the bacteria in the water. Examinations made by Frankland showed that from 80 to 90 per cent. of the bacteria may be removed in this way, and experiments made by Prof. C. C. Brown, in the St. Louis settling basins, show a quite decided reduction in the number of bacteria after 24 hours of settlement.

Efficiency of Sedimentation.—The relative economy and efficiency of the continuous and intermittent methods of operating settling basins are somewhat disputed points in this country. The practice in Europe inclines toward continuous operation. In 1886 certain experiments on this subject were conducted in St. Louis, under the direction of the Water Com-

missioner, Mr. M. L. Holman. At the time of these experiments there were in operation four settling basins at the Chain of Rocks Station, each 600 feet long, 270 feet wide and 13 feet deep. They were operated on the fill-and-draw method, one in filling, one in drawing and two in settlement. The average quantity drawn off at each drawing was from 10 to 12 million gallons. The daily average consumption was about 32 million gallons. Thus each basin had an average period of rest of from 16 to 18 hours, including the time of filling and drawing. The clarified water went to a well called the "clear well," from which it was drawn into the distribution system. The experiments on continuous flow were made with a flume $2\frac{1}{2}$ feet deep, $4\frac{1}{2}$ feet wide and about 500 feet long. The raw water taken to the flume was the same as was taken into the basins, and in the diagram is called the "Distributing Well." The relative clarification was determined by an apparatus called a comparator, which served to show the depth of the sample of water which would obscure diffused daylight, and thus indicate the degree of clarification. Its determinations while not exact, and subject to a considerable personal factor, serve as a fair guide in judging of the results obtained. These data are plotted in Fig. 2.

In this diagram is shown the degree of clarification in the different portions of the flume, as the water passed through it at different mean velocities. The figures on the right are the comparator readings; the higher the number, the clearer the water. The inclination of each line then represents the rate of clear-

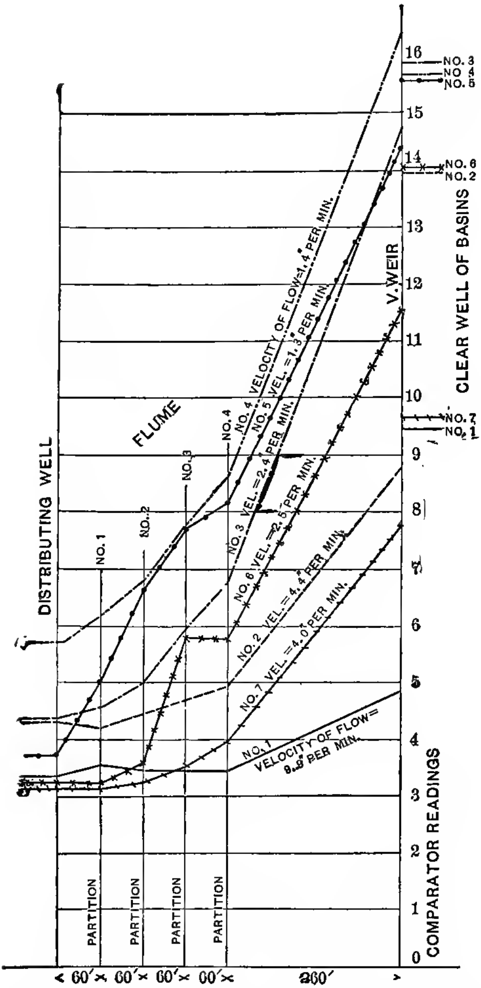

FIG. 2.—RATE OF CLARIFICATION OF MISSISSIPPI RIVER WATER AT ST. LOUIS, MO., IN PASSING SLOWLY THROUGH A LONG FLUME.

ing. The diagram shows that the greater the velocity of flow, the less rapid the clearing, and the less absolute clearing accomplished; and the slower the velocity the more rapid the clearing and the more absolute clarification accomplished in traversing the flume; and also that probably the effect of the dams across the flume was detrimental to the settlement in every case. The detrimental effect was more evident at the higher velocities. At the slow velocities of 1.3 and 1.4 inches per minute the efficiency of the continuous flow, even in this small flume, was about the same as resulted from 16 to 18 hours of quiet settlement in the large settling basins. It is probable that a velocity of 2.4 to 2.5 inches per minute would, allowance being made for the bad effect of the dams, effect a clarification practically equal to that obtained by from 16 to 18 hours of quiescent settlement, in traversing the 500 feet of flume. It is also probable that this effect might have been looked for with a length of flume of about 400 feet if the dams had been omitted.

SETTLING BASINS.

Designing.

Location.—Settling basins are sometimes placed so low that the water from the river may be flooded into them rapidly by gravity. They are frequently placed on the bank, and are filled by pumping, and they are also sometimes placed on a hill, the water being pumped into them, and, after clarification, allowed to flow into the distribution system. In Antwerp and

Rotterdam, situated on the tidal rivers Nethe and Maas respectively, the quality of the raw water varies with the tides, and the settling basins have been placed sufficiently low to permit of a whole day's supply being rapidly flooded into them when the water is in its best condition, without pumping. In several of the London works also the settling basins are lower than the rivers. In most of the German works, however, and in many of the English, the basins are high enough to be above floods and the raw water is pumped into them. At Altona the raw water of the Elbe is pumped into the basins on a high hill, flows to the filters by gravity, and thence to the city. Similar arrangements will also be necessary in some of the filter plants now being built for the city of Philadelphia.

Capacity.—The capacity which should be given to the settling basins will depend upon the purpose they are intended to serve, and will vary from $\frac{1}{4}$ or $\frac{1}{3}$ of a day's supply of water to several days' supply. If the river from which the supply is drawn is only slightly turbid, ordinarily, but is subject to being made roily for three or four days at a time, by floods of short duration, a small capacity only need be provided. If the river is constantly turbid, and carries a great or even greater proportion of matter in suspension during dry-weather flow than during floods, like the lower Mississippi, and portions of the Red, Arkansas and Missouri Rivers, a storage capacity equal to at least one or two days' supply should be provided, and very frequently chemicals will have to be employed to

bring about a secondary subsidence of the finer particles.

It sometimes happens, however, that it is desirable to have a large storage capacity for other considerations than those of economy of operation. The city of London offers an example of such conditions. The valleys of the rivers Thames and Lea, above London, are quite thickly populated, and the sewage of this population finds its way into the streams, after having been treated chemically, or by its application to land; the treatment is thoroughly carried out, however, only in times of low water. When the rivers are high, a large amount of untreated sewage goes into them, through storm-water overflows, and by direct discharge. The water companies, in order to secure the water in as good a condition as possible, pump it from the river to the settling basins only when the rivers are low, and therefore provide sufficient storage capacity to carry them over periods of high water. This has resulted in the construction of basins very much larger than would otherwise have been necessary; the different companies now having storage capacity ranging from about two to fourteen times their daily average consumption, with a tendency to still further increase the reserve quantity.

Depth.—Before determining the area required for settling basins it is necessary to decide upon their proper depth. To establish this point it will be necessary in some cases to make experiments, because the deeper it is possible to make the basins the less area will be required. Usually it will be found

that the depth can be so great that the problem becomes one of economically designing a storage reservoir to hold the given amount of water. This was found to be the case at St. Louis. In practice the depth of water is usually made from ten to sixteen feet, allowing from two to three feet of this depth for the accumulation of sediment. Since in small basins the proportionate cost of the walls around the periphery is greater than in large ones, it is evident that it would be economy to make small basins shallow and large ones deep. A less depth than about ten feet, however, would scarcely be recommended.

Length, and Velocity of Flow.—In basins to be operated on the continuous-flow method the first point to be decided is the proper velocity to be given the water in its passage through the basins.

If the flow is too rapid, eddies will be produced which will interfere with the subsidence of the finer matter. It would obviously be poor economy to construct very long basins for a water which clears rapidly, because most of the sedimentation would take place near the inlet for raw water, and the surplus length would be unnecessary. In a water which clears very slowly, however, that is, water discolored largely with clay or very finely comminuted matter, better results should be obtained by making the basins long in order to give sufficient time for sedimentation.

As to the maximum allowable velocity, authorities differ. Where the process is to be followed by coagulation or filtration, greater absolute ve-

locities are sometimes allowable than where sedimentation is the only treatment. Sedimentation alone cannot be relied on to produce sufficient clarification excepting in waters which ordinarily run clear enough for use without it. If the normal condition of the water is turbid, there is almost always a permanent discoloration due to clay and finely divided organic matter in suspension, which simple sedimentation alone would not remove in many days of absolute rest. We find, therefore, in the works which have been executed, that the assumed velocity varies very greatly, according to the judgment of the different designers. In Hamburg and Altona, which use the turbid, dark-colored water of the Elbe, the velocities are about 4.5 and 3.8 inches per minute respectively. At both of these places the water is subsequently filtered. Professor Freuhling* recommends a velocity of from about 2.35 to 4.7 inches per minute.

The data for the settling basins at several places are given in Table VI.

Having decided upon the capacity and the rates of flow through the basins, their lengths may be found. In large works the determination of the number of basins and the width of each is a matter of economically subdividing the total capacity (knowing their depth, and length, and the approximate amount of sediment to be removed in a given time) in such a manner as to leave a sufficient number of basins always in operation while one is being cleaned or repaired. The number of basins to be provided in a se-

* Handbuch der Ingenieurwissenschaften.

ries designed for the fill-and-draw method should be such as will give the longest period of rest to the standing water, regard being had to the relative economy of construction of different designs; for it must be borne in mind that the interest and sinking-fund charges are a large part of the cost of sedimentation, being nearly always more than the cost of operating and cleaning the basins.

TABLE VI.

City.	Daily Consumption.	Capacity of Basins. Gallons.	No. of Basins.	Approximate Days' Storage.	Daily Delivery, Gals. per sq. ft. of Effective Area.	Velocity of Flow in Basin. Ins. per Minute.
Antwerp.......	2,310,000	1,320,000	2	1	1277	1.75
Shanghai..	3,000,000	6,130,312	2	2	1250	.93
Baroda........	3,000,000	16,700,000	2	5.6	545	.35
Hamburg......	35,000,000	84,000,000	4	2.4	3673	4.56
Prof. Fruehlings' rec'n.	....	....	....	......	4240	2.34
St. Louis......	75,000,000	157,000,000	6	2	2232	2.50
Vicksburg......	....	1,500,000	1	......	......	.63
Altona, '90....	4,900,000	1,500,000	2	1/8	3800	3.8
London:						
Chelsea......	11,800,000	168,000,000	....	14.2		
E. London...	53,870,000	738,000,000	....	13.7		
G. Junction..	22,000,000	77,000,000	....	3.5		
Lambeth	23,538,000	153,000,000	....	6.5		
N. River	40,000,000	203,000,000	....	5.1		
Southw. and Vauxh......	44,000,000	79,000,000	....	1.8		
W. Middlesex	20,150,000	141,000,000	....	7.0		

The frequency of cleaning will, of course, depend upon the amount of suspended matter carried by the water at different times and seasons, on the water consumption, and on other factors. At times, and under

some conditions, basins may go for a year or more without cleaning being necessary, or they may require it at intervals of a few weeks.

Form.—The form to be given to the basins will depend, probably, on the configuration of the ground. Where one shape can be used as well as another, the square or circle, which take less periphery to surround a given area than an oblong or oval shape, may be advantageous. In large works basins are built in groups in order to have always sufficient storage to allow of one basin being cleaned without working the others at too high a rate. They are usually arranged side by side for the sake of economy of construction; the inlets for raw water being at one end and the outlets for the settled water at the other. At Omaha, Neb., where the water is taken from the Missouri River, it was found that sometimes clarification would not follow sedimentation, even with periods of rest up to 72 hours. The question was said to have finally been satisfactorily solved by causing the water to flow through a series of five settling basins of different sizes. The water flows from each basin to the next over wide, sharp-edged weirs, falling a height of from 6 to 9 inches, in a thin sheet, by which means aeration is promoted, in order to counteract the tendency to bad odors caused by the necessarily long period of time occupied by the water in passing through the basins. This feature was covered by patents.

Arrangements to Draw Off Water Longest in Storage.—In some places the basins are divided by longitudinal partitions in such a way as to force the water

to take a circuitous course from the inlet to the outlet, and thus insure greater certainty that the water that has been in the basin longest will be removed first, and to prevent the direct washing of the water across the basin from the inlet to the outlet. In Frankfort-on-the-Main, Mr. William Lindley has provided means to draw off the water first that has been longest in storage by a series of immersion plates, partitions extending across the basins, movable vertically in slots at each end, and slightly less in height than the depth of the water in the basins. If the water coming in from the supply main is warmer than that in the basins, the plates are drawn up so that the water to get out must go downward, thus forcing out first the water that has been longest in storage. If the supply-water is cooler than that in the basins, the immersion plates are forced to the bottom and the water is drawn off over their tops.

Locations of Inlets and Outlets.—For continuous operation the inlet should be near the bottom, at one end, and the outlet near the top at the other end. If the basin is very long the inlet and outlet might both be from 3 to 4 feet above the bottom. The opening of the inlet should be large, or perhaps it would be better to have several, entering at points some distance apart, in order to reduce the velocity of the entering water as much as possible, so as to deposit the heavy sediment near the inlets, and to improve the conditions of flow throught the basin. There is no objection to the inlet being at or near the bottom of the basin. The outlet should be at least 3 or 4 feet

below the surface, in order to exclude floating objects and to avoid the danger of clogging with ice. The successful practice of to-day indicates that floating arms and stand-pipes with many draw-off valves at different elevations are useless refinements, likely to give much trouble in cold climates; it being generally perfectly satisfactory to have the outlet of large size some depth below the surface. In fact, the outlet may be placed low enough to be used on the fill and draw method, if desired. At the St. Louis and Hamburg plants, both very large, the outlets are placed at but slight elevations above the bottoms.

Construction.

Bottoms.—As ordinarily built, after the excavations for the basins have been made, the bottom and side slopes, if the sides are not formed of masonry walls, are covered with an impervious clay-puddle carefully and thoroughly rammed and consolidated to prevent leakage. The puddle should vary in thickness according to the character of the bottom, the quality and composition of the clay, and the depth of the basins. Where the soil is firm and the puddle is a pure, clean clay mixed with about an equal quantity of gravel, a thickness of about 9 inches will suffice. If the puddle is made from a clay containing a considerable amount of micaceous material, a depth of even two feet may not be too much, if the water has to be pumped at considerable expense. The clay lining should be covered with a paving of brick, laid dry, or of concrete, in large slabs, to protect the clay from erosion,

and to facilitate cleaning. On the slopes, where ice may form, and frost cause trouble, the brick paving should be bedded in Portland cement, or the slope-lining should consist of a layer of strong concrete.

In case a good clay for puddle is not to be obtained without great expense, it may be necessary to use a lining of concrete 6 to 9 inches thick for the bottom and slopes. This has frequently been done with success. There is, however, great likelihood that such large surfaces of concrete may crack under temperature changes when the basins are emptied for cleaning and the bottom and slopes exposed to the hot sun for considerable periods of time. The danger from such cracking is not always great, but in case the subsoil when wet is of a nature to yield under pressure considerable settlement may take place along the cracks, and leaks of serious magnitude may follow. If the subsoil when wet is very firm and retentive such a danger would not be great, as the cracks might possibly silt themselves up again to a condition of water-tightness.

Instead of using such expensive methods in the construction of settling basins, it may sometimes be satisfactory to form them along the bank of the river or lake from which the water is taken, by excavating the interior space with dredges and forming the embankment along the river side from the excavated sand or earth. The faces of the slopes, inside and outside, should be protected with a thick riprap of broken stone to prevent abrasion, and the necessary inlets and outlets for the regulation of the flow

through the basins should be provided. Such basins might be cleaned at small expense by means of a suction pump, mounted on a barge. This plan was contemplated in the settling basins proposed for the Torresdale filter plant on the Delaware River at Philadelphia.*

Underdrainage.—In cases where the bottoms of the basins are lower than the water in the river, it may, if the land is porous, be necessary to underdrain the site. The drains should discharge into a sump, from which, in wet seasons, the water may be pumped, to prevent the possible breaking in of the lining, by the upward pressure of the ground-water when the basins are emptied for cleaning. If two adjoining basins are separated by a division wall of masonry, great care should be exercised in the placing of the puddle. This should be of increased thickness on each side of the wall, and should extend down the sides of it and under the footings, unless the latter be founded on rock or other impervious material. This precaution is necessary to prevent the blowing out of the bottom of a basin when its neighbor is emptied for cleaning or repairs. An accident of this kind happened several years ago to the St. Louis settling basins.

Sides.—If the sides of the basin are to be of masonry they should be designed according to the ordinary rules, as retaining walls, considering the basin empty. If the sides are simply the dressed faces of

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* Report on the Extension and Improvement of the Water-supply of the City of Philadelphia, 1899. Rudolph Hering, Joseph M. Wilson, and Samuel M. Gray.

the excavation or embankments, they should have a slope of about 2 horizontal to 1 vertical, excepting in very loose soils, when the slope should be increased to 3 to 1.

Arrangements for Cleaning.—The bottom of each basin should have a longitudinal channel through the centre, sloping, as circumstances may make necessary, toward one end or the other, with a slope of about 1 in 500. The bottom surface should slope toward this channel with an inclination of about 1 in 200, in order to facilitate the removal of the sediment. If the basins are very large, and construction expensive, flatter slopes than these may be used. At the large basins at Hamburg the bottom slope longitudinally is only about 1 in 1750. At Omaha, Neb., the bottoms of the basins, instead of being sloped in only two directions, are formed of a series of depressions, toward which the sludge gravitates or may be pushed. The sludge is taken to the clean-out conduit through a mud-valve at the lowest point of each depression. A system of four-inch water-mains, with convenient hose connections, supplies the water for washing out the basins.

Regulating Apparatus.—At Hamburg the water of the Elbe is pumped into a large channel, which supplies all the basins. As the basins lie between this channel and the filters it is necessary to regulate both the inflow of water to the basins and the outflow to the filters in order, first, that the basins may not be overflowed, and, second, that the too rapid flow of clarified water to the filters may not cause the water

PLATE III.—SETTLING BASIN, ALBANY, N. Y. VIEW SHOWING INLET FOR RAW WATER; SLOPE PAVING; CONCRETE BOTTOM, AND METHOD OF REMOVING SEDIMENT.

S.C.E.	21 - 88
[illegible]	25 - 380
Eng Rec.	38 - 8
Eng News	40 - 107
Eng Rec.	40 - 506
" News	43 3
"	44 - 522

to stand too deeply on the surface of the filters. Each basin is filled through two branch-pipes, about 3 feet in diameter and at right angles in a horizontal plane, which join in a cast-iron vertical cylinder about 4 feet 3 inches in diameter in the gate-house. The water from the canal is admitted to this cylinder by raising a double-seated valve, and then flows into the basin through the branch-pipes. When the water stands at the proper height in the basin the valve is closed.

The water flows to the filters through a regulating house at the opposite end of the settling basin, in which is placed a double-seated valve operated by a float resting upon the surface of the water in the canal leading to the filters. This regulates the amount of water flowing to the filters in accordance with the amount needed. The water enters the house through 18 rectangular holes in the wall, about three feet above the bottom. The regulating valve can also be operated by hand.

The basins have side slopes of 3 horizontal to 1 vertical. They were built upon marshy ground and are underlaid with a thick layer of clay-puddle. The bottoms and sides are paved with brick, while concrete is employed for protecting the slopes in the zone where ice forms.

At Albany, New York, the inlets are perforated with small holes above the water line of the basin, to promote the aeration of the water as it enters the basin. This is shown quite clearly in Plate III.

In the English practice the inlet is frequently a bell-mouth pipe, delivering the water at or near the bot-

tom of the basin, and the outlet merely a pipe controlled by a valve. Sometimes the outlet will consist of a stand-pipe with several valves at different elevations, or of a floating pipe, one end of which is maintained at a certain depth below the surface by a float.

Removal of Sediment.—If the basins are placed at such an elevation that they can be drained by gravity the removal of the sediment is easily accomplished by washing and pushing it toward the outlet at one end. This outlet should be large and should be closed by a penstock or sluice-valve operated from above by a spindle.

If the basins are to be operated on the continuous plan, it would be preferable to slope the bottom downward toward the inlet end of the basin and locate the outlet for sediment near the inlet. In order to facilitate the removal of the sediment it might be advantageous to provide a supply-main, with water under pressure, along the opposite end of the basin from the inlet, provided with valves and nipples for discharging water into the basin at the upper end, and thus supplying a current for the removal of the sediment by water-carriage. If the basins are to be operated on the fill-and-draw method the outlets for sediment might be preferably located on the opposite end of the basins from the inlets for raw water, and the bottom should then slope toward the outlet. In this case the necessity does not exist for the extra supply-main for washing out the basins, as the raw water may be used for that purpose. A very convenient arrangement for washing out the sediment

is in use in St. Louis. It consists of a movable siphon by which a stream can be siphoned out of a full basin for washing a contiguous empty one. The siphon is moved along as the washing progresses. Other means have to be provided for the basins on the ends of the series.

If the basins are placed so low that they cannot be drained by gravity, as at Antwerp, Shanghai, Rotterdam and at some of the London works, it will be necessary to construct in each basin a sump to which the sediment may be washed, and from which it may be removed by centrifugal or other pumping machinery.

When the outfall end of the clean-out conduit is subject to submersion by floods or tides a tide-flap should be placed over the end to protect it from silting up during periods of high water.

Roofing.—There is no necessity in this country for roofing over large settling basins. The only reasons which can be urged for such a practice would be to prevent the formation of ice, to protect them from the winds, and from light. Basins, as usually built, are of such depth that the formation of ice will not cause serious inconvenience; the reduction of their capacity, by the ice, will not be significant, because, during cold months, the draft will generally be light, and the water will, as a rule, contain less suspended matter than in the summer months. The effect of the wind on the rate of sedimentation will be very slight, as the action of waves in causing eddies below the surface is quite insignificant, as a rule, in such small areas

and in waters of such small depth. If it should be found, however, that there was a retardation of sedimentation, or that the waves were apt to damage the walls or slopes of the basins, the trouble could easily be remedied by a series of floating spars resting upon the surface of the water. This expedient was resorted to with success in the very large sewage precipitation tanks at Manchester, England, which are in a position exposed to very severe winds.

The necessity of protecting basins from the light vanishes if their storage capacity does not exceed a day or two's supply; if objectionable odors or growths of algæ should result, on longer storage, a simple treatment by aeration, before storage, might be sufficient to remove the objectionable qualities. As to whether the benefits arising from covering the settling basins, due to maintaining the water at a higher temperature in winter, and thus favoring more rapid sedimentation, would offset the increased cost of construction, and also of operation, it may be, in the light of our present experience, answered in the negative.

Cost.—The cost of sedimentation basins depends upon so many local conditions and circumstances, that a comparison of the data of different basins would give a very wide range of costs. Basins of about 3,000,000 gallons capacity, with concrete bottoms, 12 inches thick, on 12 inches of puddle, and with concrete sidewalls, including the iron work, masonry, intake well and connections, but excluding the cost of land, will cost not far from $9,000 per

million gallons of capacity. Those in which the bottoms and sides are puddled with clay and paved with brick will probably cost less than this; and others in which the bottoms are of concrete, laid on a puddle-bed, with asphalted joints, may cost more. The average actual cost of the reservoirs of the Philadelphia water-supply has been about $4,051 per million gallons of capacity, ranging from about $3,300 to $4,300.

Operation.

The water should be taken into the basins when in its best condition. In tidal streams, as already noted, there will generally be times when the water will be more pure than at others. Therefore, under these circumstances, the basins should, if possible, be so arranged and placed that they may be flooded very rapidly, and the intake and conduits should be correspondingly large. Where there is no apparent change of quality in the water, due to a periodically recurring cause, the water may be taken from the river from near the surface.

Rate of Flow.—If the settling basins are operated continuously, local conditions must determine how the rates of flow should be regulated. Where the basins are joined to a common conduit, leading to pumps, the regulation of inflow and outflow can safely be effected by the attendants. Their duty in this case would be to see that certain maximum and minimum depths of water in the basins and conduits were not passed, and that the rate of delivery from each basin did not exceed the limit determined upon

in the design. The fluctuating draft from the city, varying with the seasons, days and times of day, makes the work thrown upon the basins very variable unless the water goes to storage reservoirs before being delivered into the mains. Where sedimentation is not to be followed by filtration it is not often that this could be the case, as in such works the basins themselves must provide the storage to meet this fluctuation.

The labor necessary to effect the regulation for the fill-and-draw method amounts in large plants to about 25 cents per million gallons. For the continuous-flow method it is less than half of this, as it may be done by automatic apparatus similar to that already described as being in use in Hamburg.

Amount of Sediment to be Expected.—The amount of matter that will subside from a turbid water is very difficult to estimate, analyses even affording but little guide as to what may be expected. This may be seen from the data compiled in Table VII.

TABLE VII.

River and Place of Observation.	Cu. yds. Sediment per Million Gallons.	Observer.	Date.
Mississippi, St. Louis	9.1	McMath.	1879
" " "	3.3	Miss. River Comm.	80–81
" Helena......	3.9	Johnson.	1879
" Hannibal	.82	Miss. River Comm.	1880
" Prescott......	.60	Clarence Delafield.	80–81
" Clayton......	.18	" "	80–81
Sacramento River........	27.30	Le Conte.	1879
Garonne, Bordeaux.......	6.20	M. R. de Volontat.	1874
" "	.59	" " " "	1875
Mississippi R., Vicksburg.	5.20	C. R. McFarland.	1895

Table VIII shows the analyses of the Garonne waters at Bordeaux. The quantities are averages for each month from 1870 to 1874, as determined from samples taken from the surface of the river at high tide.

TABLE VIII.

Month.	Cu. ft. of Sediment per Million Gals.	Month.	Cu. ft. of Sediment per Million Gals.
January........	31.26	July..........	49.26
February......	31.68	August........	104.75
March.........	18.32	September....	171.19
April..........	17.91	October.......	147.80
May...........	16.07	November	81.53
June..........	17.58	December.....	25.79

The amount of sediment removed yearly by manual labor, from 1884 to 1895, from the settling basins at St. Louis, is given in Table IX.

TABLE IX.

Year.	Cu. yds. of Sediment Removed from Basins.	Millions of Gallons Pumped to Basins.	Cu. yds. of Sediment per Million Gallons.	Cost of Removing Sediment.
1884–5	153,000	9,564	15.997	$3276.00
1885–6	109,000	9,925	10.982	2195.36
1886–7	124,000	10,979	11.294	2137.50
1887–8	143,000	11,665	12.336	1865.41
1888–9	174,000	11,644	14.943	2869.60
1889–90	144,750	11,939	12.124	1386.00
1890–1	207,800	13,178	15.768	1411.20
1891–2	210,600	14,602	14.423	2286.40
1892–3	160,000	16,448	9.725	2810.88
1893–4	148,000	17,448	8.482	3519.20
1894–5	208,000	16,257	12.794	2668.20

The actual quantity of suspended matter removed by subsidence has been from three tenths to four tenths in excess of these quantities.

Depth of Sediment to be Provided for.—The depth of sediment which should be allowed to collect in the basins before cleaning them will vary according to the nature of the sediment and the design of the basins. If the sediment is very heavy the basins may require more frequent cleaning than if it is of lighter specific gravity. At Altona it is reported that two feet of sediment collected in the basins in three months. At Hamburg provision is made for a depth of about three feet of sediment, which here is of light specific gravity. At Antwerp about one foot in depth is allowed for.

Periods of Cleaning.—Table X, compiled from the annual reports of the Water Commissioner of St. Louis, illustrates some of the practical considerations that govern the times of cleaning the basins at that city.

TABLE X.

Date.	No. 1.		No. 2.		No. 3.		No. 4.		Cost.
	a	b	a	b	a	b	a	b	
April, 1893	....	....	....	....	....	....	36	24	$ 165.00
July	50	35	....	....	....	....	....	....	572.20
August	10	7	66	48	66	48	13	9	1296.00
September	....	....	....	....	....	....	53	39	418.80
October	36	24	20	12	....	....	....	....	312.80
November	....	....	10	6	20	12	18	10	227.20
March, 1894	14	8	20	10	20	10	14	8	527.20
May	46	24	46	24	46	24	40	20	781.60
July	70	40	78	48	78	46	78	46	743.40
October	50	30	54	36	54	36	54	36	864.80
March, 1895	18	9	18	9	20	10	....	....	278.40
	294	177	312	193	304	186	306	192	6187.40

Column a gives total depth in inches of sediment in basin.
Column b gives depth of sediment removed by manual labor.

The total amount of sediment collected from April, 1893, to April, 1894, was 222,000 cubic yards, of which 148,000 cubic yards were removed by manual labor. For the year 1894–5 the figures were 356,000 and 208,000 respectively.

A study of this table shows that the greatest amount of sediment is collected, and therefore the most frequent cleaning is needed in the summer months, from March to October. The maximum rate of precipitation occurs about July, which also corresponds in general to the periods of high water, and to the time of the year when the water consumption is greatest. From October to March the river is low, excepting for the flashy rise due to the January thaws, the consumption of water is below the average and the amount of sediment collected very small. The times of cleaning, therefore, beginning with the month of March, are at intervals of two months, two months, three months and five months.

Amount of Water Necessary for Cleaning.—The amount of water necessary for cleaning out a basin will depend upon the slope of the bottom, the nature of the sediment, the judgment of the men, and the manner in which the cleaning-water is used. The work of removing the sediment is done partly by the water and partly by hand.

With a certain cross-section of channel in the centre of the basins and a given slope, it is possible to move only a certain quantity of sediment in the water used for washing. Basins in which the bottoms are comparatively flat will, therefore, take a greater

quantity of water and a longer time to clean than those in which the inclination is greater. There are no available published data concerning the absolute amount of suspended matter that can be carried in water flowing in open troughs or channels of different dimensions and at different slopes. Probably, the more finely comminuted the matter, the greater absolute weight of it can be carried by the water at any given velocity. The removal of the sediment by water-carriage is brought about by two agencies—the power of the water to carry a part of the matter in suspension and its power to roll on the bottom particles larger than it can carry in suspension. Both of these effects are produced at a loss of energy. Velocities of flow in the clean-out conduit, calculated according to the usual rules, will, therefore, be too great. If the slope of the conduit were proportioned so that the velocity for clean water would be from about 10 to 12 feet per second when running half full, it is probable that the sediment could be carried through it without too great an allowance of flushing-water. This velocity would probably carry off a sandy sediment to the extent of about 5 per cent. of the volume of the wash-water. If the sediment were more earthy, possibly as much as 10 per cent. could be carried out. This would be of the consistency of the average sewage-sludge resulting from chemical deposition.

The amount of sediment carried in flowing rivers is very variable. Such measurements as have been recorded show a range of from about one two-hun-

PLATE IV.—ALBANY FILTRATION PLANT. GENERAL VIEW OF SETTLING BASIN, SHOWING REMOVAL OF SEDIMENT DEPOSITED FROM THE WATER.

dredths of 1 per cent. to about 1 per cent. of the volume of flowing water.

The amount of water used in washing the sediment out of the basins will, therefore, probably amount to from 10 to 20 times the volume of sediment removed.

Methods of Cleaning.—The cleaning is done by the action of flowing water, combined with labor, both so directed that the sediment is pushed and washed into the central channel and finally into the clean-out conduit. The expense of cleaning is therefore divided into two parts—wages of laborers and cost of wash-water—because of the water having to be pumped. The expense of pumpage is present in every case but one. If the basins are placed lower than the river, so that the water flows into them, the expense of pumping falls on the sediment-laden water, which must be removed from the basins. The only case where the expense of pumping can be avoided entirely is where the settling reservoirs are located at the site of a fall, or dam of considerable height, so that the water may be flooded into the basins and the wash-water allowed to flow out by gravity. This is a condition, however, that will rarely be realized.

The method of cleaning the settling basins at Albany, N. Y., is illustrated in the photographic views, Plates III and IV.

In cleaning the St. Louis basins the upper semi-fluid part of the sediment, about three tenths to four tenths of the total amount in the basins, goes out without the necessity of manual labor in its removal. The remaining six tenths to seven tenths is removed

partly by water and partly by being pushed to the outlet with squeegees.

Cost of Removing Sediment.—The cost of removing the sediment, per million gallons of water, will vary with the seasonal changes in the character of the raw water. Estimates of this sort, therefore, are difficult to make and can serve only as a rough approximation. Mr. Wm. H. Lindley gives the cost of subsidence in covered reservoirs, in Germany, including interest and sinking fund, at from $1.80 to $2.25 per million gallons, of which from 50 to 60 per cent. is for interest and sinking fund. Taking the values given in the reports of the Water Commissioner of St. Louis for 1894 and 1895, the cost per cubic yard of sediment removed from the basins, for maintenance and cleaning, for the two years would be as given in Table XI.

TABLE XI.

	1894	1895
	Cents per cu. yd.	
Pay-roll, gatemen, foremen, etc	2.1	1.4
Pay-roll, labor, cleaning basins	1.6	.8
Repairs and maintenance of basins	2.3	2.8
Water used in cleaning (estimated by author)	1.0	1.0
Total	7.0	6.0

Since 1884 the average amount of sediment removed from the water has been about 12.5 cubic yards per million gallons, which, at 7 cents per cubic yard, would make the cost about 87.5 cents per mill-

ion gallons, exclusive of interest and sinking-fund charges. The charges for these items, per million gallons, will depend upon the amount of water clarified, that is, on the speed with which the water is passed through the basins. As they are now operated, on the fill-and-draw method, this charge cannot be much less than about $3.00 per million gallons. It must be remembered, however, that the basins have a capacity for two days' supply at maximum draft, and that if the consumption should greatly increase, the same basins would serve without it being necessary to increase their capacity, although certain changes in details might be advisable to reduce the cost of operation. When operated to their maximum capacity, the total average cost of removing the sediment might be from $2.25 to $2.50 per million gallons of water passed through the basins.

Relative Advantages of Fill-and-Draw and Continuous Operation.—The principal advantage of the fill-and-draw method is that a more perfect quiescence of the water may be obtained, and for this reason, perhaps, a greater quantity of suspended matter may be precipitated in a given time. This advantage has not, however, in many works which have been executed, been found sufficiently great to counterbalance the disadvantages in point of cost of construction and cost of operation. If the sediment is heavy, and settles rapidly, the greatest bulk, under the continuous method, will subside near the point where the raw water enters the basin. Under the fill-and-draw method the sediment will be spread further away from the

inlet-pipes by the currents, as the basin fills. Therefore, if the clean-out conduit from the basin must be located near the inlet for raw water, the continuous-flow method will deposit the sediment where it will cost less for its removal than the fill-and-draw method. On the contrary, if the clean-out conduit is on the opposite side of the basin the fill-and-draw method will be the most economical in point of cleaning. If the construction of the settling basins is preparatory to a process of filtration, still other considerations may have weight in their design. Local conditions will then have to decide whether their operation should be continuous or on the fill-and-draw plan. If the basins can be placed higher than the filters, it may be advantageous to use the fill-and-draw system; if not, it will generally be necessary to operate them continuously, because, even if pumping has to be resorted to between the basins and the filters, it will be on the side of economy to reduce the lift on the pumps as much as possible.

CHAPTER III.

THE PURIFICATION OF WATER BY SLOW SAND-FILTRATION.

INTRODUCTION.

Types of Filters Used for Filtration of Municipal Supplies.—Filtration, in the sense in which the word is used in this work, has for its object the removal from water of objectionable polluting matter that cannot be economically taken out by simple subsidence, or by chemical treatment. The successful filtration processes for purifying the water-supplies of cities and towns may be separated into three classes. The distinctive characteristics of these classes are as follows: In one, first adopted in England, the water is filtered slowly through beds of sand; filters of this type are called English Filters, Slow Filters or Slow Sand-filters. The second type, a distinctively American invention, filters the water rapidly through beds of sand, a coagulant having first been added to the water; filters of this kind are called American Filters, Mechanical Filters or Rapid Sand-filters. The third type filters the water through a strainer of fine mesh, such as porcelain, concrete slabs, etc. All these methods are in use. For the sake of uniformity, in the present work the terms Rapid and Slow Sand-filters will

be used in referring to the first two types, because they are short, distinctive and sufficiently exact.

Slow Sand-filtration.—The process of slow sand-filtration consists of passing the water downward by gravity through beds of sand of certain depth, and with certain restrictions as to velocity and manipulation that experience has shown to be necessary. By this process most of the suspended matters in the water, including nearly all of the bacteria, are retained upon the surface of the sand; most of the remaining bacteria are destroyed in the top layers of the filter, while a portion of the dissolved organic matter in the water is converted, by chemical action, into inorganic compounds.

Rapid Sand-filtration.—The process of rapid sand-filtration consists of passing the water downward at a rapid rate through small beds of sand, a certain amount of coagulating material having been first introduced into the water to assist in forming a scum on the surface of the sand and a film between the grains of sand in the bed. The bacteria and suspended matters in the water are largely retained in the filter-bed. The coagulant may also reduce the color and dissolved organic matter in the water to a much greater extent than would be possible with slow sand-filters.

Which of these methods of purification is preferable, in any given case, must be determined from careful considerations of the quality and character of the water, the results desired and the relative costs of the processes both for installation and operation.

THEORY OF SLOW SAND-FILTRATION.

The foreign substances carried in water are either mineral or organic, and they are dependent, to a certain degree, on each other. The organic matter is found first as living organisms, vegetable or animal, which float or have the power to move about in water; second, as the products of organic life, such as albumen, urea and tissue, which may be dissolved in the water or suspended in it, and third, as products of the decomposition of organic matter. In the latter class belong the salts of ammonia and of carbonic and nitric acids, which are absorbed by growing vegetation as food. The carbon and nitrogen in organic matter are constantly changing from organic to mineral matter and back again. The organic matter found in water consists mainly of carbon, hydrogen, nitrogen and oxygen. The process of decomposition may be said, in a general way, to consist of first the oxidation of the carbon, which leaves the nitrogen combined with hydrogen in the form of ammonia, and subsequently the union of the uncombined oxygen with the ammonia, converting it into nitric acid and water. This series of changes requires the presence of oxygen and of some earthy or alkaline base in the water with which the acids can combine, when formed. Further, the presence of certain micro-organisms is necessary to initiate and carry the process through to completion.

In surface waters there are, therefore, constantly going on two actions, assisted by contact with the

air and the action of the sun's light and heat. These are the oxidation of the elements of the organic matter, and their absorption by the various forms of vegetal and animal life. This process only goes on in the presence of light. In pure ground-waters we fail to find the presence of nitrates, but in ground-waters previously polluted, and in the bottoms of deep ponds, reservoirs or lakes we often find, due to the absence of uncombined oxygen and to the absence of light, the presence of free ammonia and nitrites, intermediate products of the regeneration of decaying organic matter. The plant-life which results from the absorption of the oxidized ammonia is called in chemical analyses, the albumenoid ammonia.

Shallow stagnant bodies of water, which in the heat of summer are full of animal and vegetal life, become foul in time because decay gets ahead of growth, and the products of decomposition accumulate.

The color acquired by surface waters, apart from turbidity, is derived from leaves, grass, peat, etc., by long contact. It contains considerable nitrogen, and is usually very stable in character. For the removal of this matter it is necessary to treat the water with hydrate of aluminum, which combines with the coloring matter and gives a clear, colorless water on the precipitation of the coagulant, or its removal by rapidly operated filters.

Pure water should have no odor. If the odor is caused by dissolved gases, it will leave when the water is boiled. If it comes from suspended or dissolved organic matter, it may vanish when the water is

boiled, but may again develop. The odors from suspended organic matter and vegetation may sometimes come from the decay of the matter, but often they are caused by the organisms themselves. Sometimes the removal of odors is a difficult matter, requiring a special line of treatment.

As stated before, the change of the decaying matter from organic nitrogen into the salts of nitric acid can only be brought about in the presence of bacteria. The fact had long been known, but it was not until about 1890 that it was possible to isolate the nitrifying organism. In that year, by the independent labors of Edwin O. Jordan and Mrs. Ellen H. Richards, of the Massachusetts State Board of Health, Dr. Percy F. Frankland and Grace Frankland and Winogradsky, abroad, the organism was isolated; since that time much intelligent investigation has been undertaken to determine the conditions which are most favorable for the life, propagation and activity of the organism.

The organism is present and active in the presence of oxygen, in all normal surface waters and probably also in falling rain. Among the conditions which are essential to the activity of the organism are the presence of oxygen, organic matter, moisture and some alkali and a temperature suitable to foster the growth of vegetation. In slowly passing water containing these necessary ingredients through beds of sand, the conditions for rapid nitrification are gradually established. The nitrifying organisms in the applied water become attached to the sand grains, mostly in

the upper layers of the sand, and attack the organic matter in the water, which, to a considerable degree, appears to unite with certain constituents of the filtering materials. The organic matter is resolved finally into soluble mineral salts, which pass out in the effluent. The conditions under which the most perfect chemical purification takes place seem to be also the most favorable for the removal of the bacteria in the applied water. The cause of the death and destruction of the bacteria may lie partly in the absorption of the oxygen of the applied water in the process of nitrification, but probably they are themselves oxydized the same as other organic matter. It cannot be said they die from lack of food-supply or lack of oxygen, for there is generally a sufficient amount of ammonia in the effluents of filters to support a considerable bacterial life; and it is known that there are certain species of bacteria that can live without the presence of oxygen.

Action of Slow Sand-filters.—Recent investigations have demonstrated that in slow sand-filters in efficient service, showing a normal reduction of bacteria, a film of gelatinous material forms around the sand grains whereby most of the bacteria are mechanically retained under conditions that are not favorable for their existence. This gelatinous material is composed probably, in part, of dead or resting bacteria.

Efficiency.—In discussing the results obtained by slow sand-filtration there are three phases which should be considered; these are: bacterial efficiency, bacterial purification and hygienic efficiency. As the

result of the experience of many years, it is known that the number of bacteria found in the effluents of slow sand-filters does not necessarily represent the number which have passed through with the water, and hence bacteriological analyses of filter-effluents may not be a correct index of the percentage removal of the bacteria. A large number, and in some cases all, of the bacteria found in the effluent, grow in the lower part of the filters and the underdrains, and there is as yet much difficulty in distinguishing between the latter and those which pass through with the water. Plagge * holds the view that even disease germs may multiply in badly managed filters.

The bacterial efficiency is the percentage which the number of bacteria found in the effluent water is of the number of bacteria in the raw water. The bacterial purification is the percentage which the bacteria actually removed by filtration is of the number of bacteria in the water applied, and is considerably higher than the bacterial efficiency. The experiments with special growths of bacteria at the Lawrence Experiment Station, in 1894 and 1895, indicate that the normal bacterial purification from slow filtration ranges from 99 to 100 per cent. The hygienic efficiency is regarded as the percentage removal by filtration of the bacteria capable of producing disease. The hygienic efficiency is probably fully as great as the bacterial purification.

* Untersuchungen über Wasserfilter. Veröffentl. aus dem Gebiete des Militär-Sanitätswesens. Med. Abth. des koenigl. preuss. Kriegsministerium, Berlin, 1895.

The percentage basis of expressing bacterial efficiency is unfair because with water low in bacteria the percentage will be very high, but with polluted water it may still be high and yet allow a great number of bacteria to appear in the effluent. The German standard of 100 per c.c. seems to be based on a more rational idea, but this is also open to the objection that it is not universally applicable. If, for instance, the water were sewage polluted there might be many pathogenic bacteria in this 100, while if the water were not sewage polluted, but contained several hundred of the ordinary water bacteria, it would be perfectly unobjectionable. Such results must, therefore, be interpreted with a knowledge of the character of the raw water as to sources of pollution.

Influence of Character of Water.—The influence of the character of the water upon the results of slow sand-filtration is very decided. The available information shows clearly that there are some waters saturated with oxygen and containing small amounts of organic matter, which may be successfully purified by continuous filtration. On the other hand water containing very little or no free or dissolved oxygen, and large amounts of organic matter, cannot be purified successfully by the continuous method, but will require an intermittent application of the water to the filters in small doses whereby a sufficient amount of oxygen is carried down into the sand to effect the requisite oxidation.

The results obtainable, therefore, in the filtration of a polluted water may vary with seasonal changes, ac-

cording to the amount of free oxygen in the water. When the oxygen is high the rate of filtration may also be high. The amount of oxygen present in the water may be an indication of whether the water should be filtered intermittently or continuously. The experience at the Lawrence, Mass., Experiment Station has shown that free oxygen is never absent from the effluents of slow sand-filters at the station, although, at times, the percentage is very low, particularly in the filters operated continuously. The fact that the amount of free oxygen in water is least in summer weather, when the organisms of nitrification are most active, is significant. In Lawrence the percentage of dissolved oxygen in the Merrimac River and in the effluents of the water-filters decreases gradually from the winter months to the middle of September, and then gradually increases again as the winter months return. It is also noted that the effluents from the intermittent filters contain, almost uniformly, a higher percentage of dissolved oxygen than the effluents from the continuous filters. The general results obtained from the Lawrence experiments indicate that in the treatment of the Merrimac River water by slow sand-filtration it is possible to remove all the suspended matter, and a variable amount of the color and dissolved organic matter, and that old filters are as efficient as new in removing albumenoid ammonia. The experience in regard to the removal of suspended matter at other experiment stations has shown, however, that slow sand-filters may fail to give satisfactory results in this regard.

Influence of the Size and Character of the Sand on the Efficiency of Slow Sand-filtration.—The physical characteristics of sand may be determined by sifting several samples through a series of sieves of different meshes, and then determining the percentage by weight of each size and the relations the different samples bear to each other. Using the nomenclature of the Massachusetts State Board of Health,* the Effective Size of a sand is the size of the grain in millimetres, such that 10 per cent. of the grains in the sample is finer than itself, and the Uniformity Coefficient expresses the ratio of the size of grain such that 60 per cent. is finer than itself to the size such that 10 per cent. is finer than itself. Since the purification in the filter is brought about by the passage of the water between the sand grains, it is evident that the presence of large stones in the sand will not add to its value; the smaller the percentage of particles of larger grain than those of the effective size, the less waste material there will be in the filter, and the more uniform will be the passage of the water through it in all parts of the beds, both as to velocity and as to quantity.

Influence of Compacting of Sand.—The resistance to the motion of the water through the sand, due to the compacting of the surface under service, gradually, to a slight extent, reduces the capacity of a slow sand-filter plant. This is caused partly by the settling of

* For methods of analyzing sands, see article by Allen Hazen, in Report of Mass. State Board of Health, 1892.

the sand in the water and the compacting of the surface by the workmen in cleaning.

Sand, to be suitable for filter purposes, should be free from clay or calcareous materials, as these have a tendency to cement the sand grains together and produce other disturbing elements tending to reduce the efficiency, both by increasing the frictional resistances and by producing sub-surface clogging. The grains of sand should also be as uniform in size as possible, because the greater the variation in size, for any given effective size, the more compactly the sand will settle under the action of the flowing water, and the greater the frictional resistances will become. The filling of the filters from below, as well as the escape of air upward through the sand, will tend to readjust the grains, and if there is a great variation in their size, they can pack more closely than if they are all of one size.

The available information regarding the effect of the size of the sand grains on the efficiency of a given sand in removing bacteria, in a filter which has been in service a long time, shows little to warrant the belief that the efficiency depends much on the effective size, within certain limits. The experience at the Lawrence Experiment Station goes to show that the percentage of bacteria which will pass through filters with sands of effective sizes of .14 to .38 millimetres, which have been long in service, is practically independent of the effective size. (See Fig. 3.) The number of bacteria in the effluent seems to depend more on the number in the applied water than upon any

other factor. Even sands with an effective size of .48 millimetres show as high bacterial efficiency as the finer sands, but require a longer time to give normal results. Observations on filters of coarse sands, in

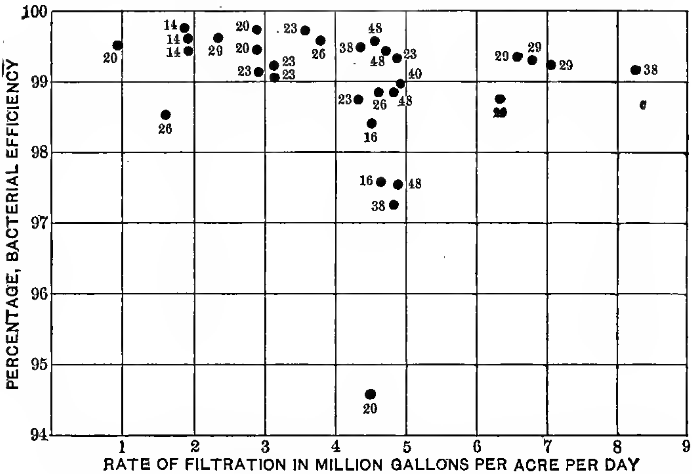

FIG. 3.—EFFECT OF SIZE OF SAND GRAINS ON EFFICIENCY OF FILTRATION.

operation since 1889, go to show that as they grow older in service, they resemble more and more filters of fine sand. The chief points, however, in which the size of the grains has the most influence are that filters of coarse sand require a longer time, after being placed in service, to yield effluents of normal bacterial contents, and they are more sensitive to disturbing influences than filters of fine sand.

Influence of Depth of Filtering Materials.—The influence of the depth of the filtering material on the efficiency of filtration is felt principally in the steadying

action afforded by deep layers on the velocity of flow of the water through the sand, and by the bacterial action which takes place in the lower part of deep filters. While deep filters are more efficient than shallow ones, the latter are fairly satisfactory under favorable conditions. As far as the data now at hand can be interpreted, it seems that a depth of 12 inches in a filter long in effective service, will give nearly as good results as a greater depth, provided there is no outside disturbing influence; but if such disturbance should occur, its effect upon the efficiency of filtration will be more marked and of longer duration than in the case of deep filters.

Fig. 4, which shows the average results from analyses of the materials of ten filters 5 feet deep at the Lawrence Experiment Station, exhibits the accumulation of organic matter and bacteria in slow sand-filters in successful operation. Four of these filters were intermittent and six were of the continuous type. The diagram shows that the greatest amount of the work, in the retention of the bacteria and stored nitrogenous matter, is being done in the top 6 or 8 inches of the filters, and that all but an insignificant proportion of the bacteria and nitrogen are retained in the upper inch. As the depth below the surface increases the number of bacteria and percentage of stored nitrogen decrease very rapidly until a depth of about 1 foot is reached, and then more slowly, but still perceptibly up to about 3 feet or more. The stored nitrogen below this depth may represent, according to Mr. Clark, the normal quan-

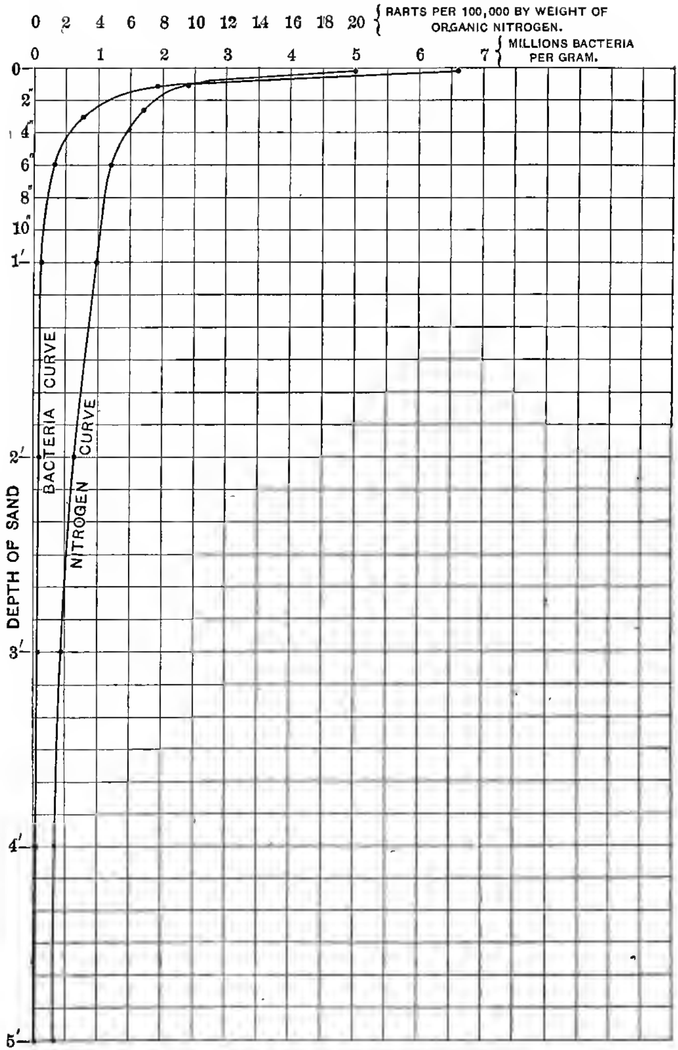

FIG. 4.—DIAGRAM SHOWING THE RETENTION OF BACTERIA AND STORED NITROGEN IN TEN SLOW SAND-FILTERS AT THE EXPERIMENT STATION, LAWRENCE, MASS.

tity which existed before the filters were placed in operation. This nitrogenous matter in the filters is the film of gelatinous matter arranged around the grains of sand; its existence in the lower portions of deeper filters in part explains the greater and more uniform efficiency of deep filters in removing bacteria.

Because of their greater sensibility to disturbing influences, filters of a depth of 1 or 2 feet would not be so reliable in operation as deep filters. Experiments made at Lawrence on scraping filters 2 feet deep and 5 feet deep respectively, showed that scraping did not affect the number of bacteria in the effluent of the filter 5 feet deep, while in the shallow one scraping was almost invariably followed by a large increase in the number of bacteria passing through, and caused Bacteria Prodigiosis, applied with the water, to appear in the effluent for 3 or 4 days following the scraping. Numerous other records testify to the greater reliability of deep filters, and good practice, in the light of this experience, would require that filter-beds be made from 4 to 5 feet deep, according to circumstances.

The usual European practice is to give the filtering materials a depth of from 2 to 4 feet, and to allow this depth to be diminished by repeated scrapings, as the beds clog, to from 1 to 2 feet. When the minimum allowable depth has been reached, the sand taken out in the periodical cleanings is replaced and the filter brought back to its original depth. In Germany the Imperial Board of Health has specified that the sand should never be reduced to less than 12

inches in depth by cleaning, and, when possible, a greater depth than this should be maintained.

The effect of the uniformity coefficient and the size of the sand have already been discussed. There is another qualification necessary for effective operation, respecting the filtering materials. That is, the necessity for exercising great care in the sorting and placing of the sand in the filter. Layers of fine sand or loam in the body of the filter must be guarded against, as they will cause sub-surface clogging, and therefore reduced efficiency. Such layers have been tried in Holland, and have been experimented with at Lawrence, always with the above result. It is advisable to have the sand as nearly uniform as possible in size of grain from top to bottom of the filtering material, and to so place the sand in the beds that there will be no planes of lamination or layers of different degrees of compactness.

Effect of the Loss of Head Upon the Efficiency of Slow Sand-filters.—The difference of level between the height of the surface of the water on the filters and the height to which the water would rise in a vertical pipe attached to the outlet of the underdrains, when the filter is in operation, is called the Loss of Head. This loss of head measures the resistance offered to the passage of the water through the filter, and depends upon the quantity of water filtered per unit of time, the age of the filter and other causes. It has been the general European practice to limit this loss of head to from 24 to 30 inches, in the belief that high heads compact the sand and also cause local

breaking of the fine sediment layer on the surface, thus permitting water to pass through at greatly increased rates with resulting reduced efficiency.

The experience of recent years, however, at the Lawrence Experiment Station, has pointed to the conclusion that neither of these circumstances exercises an important influence toward deterioration in the bacterial efficiency in properly operated filters, when the loss of head is allowed to equal the combined depth of the sand and its covering of unfiltered water. In some cases abnormally great numbers of bacteria were obtained under high heads, but their presence was satisfactorily explained in most cases. Under some conditions, however, as found at Cincinnati by Mr. Geo. W. Fuller, a head greater than the depth of the water over the sand was found to be detrimental, because the water contained a large amount of air in solution which was liberated when the head became negative; and this, rising in the form of bubbles, disturbed the filtering materials and brought about reduced efficiency. Generally speaking, negative heads should be avoided when possible, though their use may not always be unsatisfactory. In many of the European filters the loss of head is limited by the method of construction of the beds. At Berlin the limit is about 24 inches and at Hamburg about 28 inches. The idea is commonly held abroad, however, that not only are high heads dangerous, but that after a limit of about 2 feet has been reached the head will increase in a very much more rapid proportion than the quantity

of water filtered between scrapings. I can find no careful investigations of this subject, however, excepting those of the Massachusetts State Board of Health. This is a question that vitally concerns the cost of operation, because the less frequently the filters require cleaning, the less will be the cost of operation. In removing the film of sediment on the surface of the filter practical considerations make it impossible to remove less than a certain depth of the material at one time. This depth is, within limits, independent of the quantity of dirt that has accumulated, and any expedient that will lengthen the period of time between scrapings will result in a corresponding reduction of the quantity of sand to be washed per unit of water filtered, as well as a reduction of area of filter necessarily out of use during cleaning. The use of high heads will therefore allow of a greater length of time between cleanings than low heads, in waters which can be successfully treated by slow sand-filters. The experiments with the Lawrence experimental filters seem to indicate that the quantity of Merrimac River water which can be filtered between scrapings is almost proportional to the maximum loss of head allowed, and to the quantity of water filtered per acre per day, up to about five million gallons, and that very fine sands require more frequent scraping than medium or coarse sands.

The great difference in physical characteristics and chemical constituents of waters from different sources, and at different times of the year, makes it impossible to state that the use of high heads is

always advisable from the point of efficient and economical operation. The indications, however, point to the advisability, in all cases, of studying carefully the particular water in question, at various seasons of the year, to determine what effect high heads would have and their bearing on the design of the works.

Effect of the Depth of Water.—There are few available data on the effect of allowing the water to stand at a considerable depth over the sand in the filters. Usually economical construction establishes the limit. This is ordinarily from 3 to 5 feet in the European filters; it is seldom less than 3 feet, particularly in open filters where ice is apt to form, and seldom more than 5 feet except when the thickness of the sand layer has been reduced by frequent scraping. It is not probable that very much greater depths would have any unfavorable effect, either on the ability of the filter to pass large quantities of water, at reasonable rates, or on its bacterial efficiency.

Effect of the Rate of Filtration on the Bacterial Efficiency.—The European engineers generally incline to the belief that low rates of filtration are necessary to high efficiency. Thus, the rate allowed at Hamburg is 1.6 million gallons per acre per day, and at Berlin 2.57 million gallons. Most of the other German works keep below this latter limit, while in the English practice the rate is generally under two million gallons per acre per day. If it is possible to successfully use higher rates than these it is evident that a saving may be made in the area of the filters, and

thus in the cost of construction, as well as in the operating, interest and sinking-fund charges. We have evidence, in some cases, that rates very much higher than these have been successful. The question is one that must be specially decided for each locality. Thus at Zurich, Switzerland, the water is often comparatively low in bacteria, but high in constituents for the formation of the surface film, and being free from turbidity, allows of rates at times exceeding ten million gallons per acre per day, with excellent results. At Lawrence the rates have occasionally been, with old filters, as high as ten million gallons per acre per day in successfully filtering the Merrimac River water. Such high rates, however, are not recommended for continuous use.

As waters vary greatly in their chemical, bacterial and physical characteristics, and in the amount and fineness of sediment carried in suspension, no hard and fast rule can be made for the best allowable rate; this can only be approximated in advance by estimate and finally determined by actual experience. Waters which are normally very high in bacteria, or in organic matter, or which are deficient in the kind of organic matter necessary for the formation of the gelatinous film around the sand grains, or which contain a considerable amount of finely comminuted clay in suspension, will require lower rates than waters of the opposite characters. We find this condition prominently recognized in the European works. The Hamburg rate of 1.6 million gallons per acre daily for the black, muddy, polluted water of the Elbe,

after from 15 to 30 hours of settlement; the Berlin rate of 2.57 for the ordinarily clear waters of the Spree and Havel, and the Zurich rate of about 7.5 million gallons per acre per day for the perfectly clear lake-water, are probably the result of experience with satisfactory bacterial purification and economy of operation in view. With the water of the Merrimac River, at the Lawrence Experiment Station, perfectly satisfactory purification has been attained for long periods of time in filters of considerable age, with rates up to 7 million gallons per acre per day, and in some cases even with rates reaching 10 million gallons.

The deleterious effects of high rates will be felt very much more in filters with thin than with thick sand layers, and also the effects will be more noticeable in a new filter than in one which has been in service many months.

Effects of Sudden Changes in the Rate of Filtration.—The results obtained at the Lawrence Experiment Station indicate that sudden changes of rate should be avoided, as they are likely to directly affect the bacterial purification. Generally speaking, an increase of rate above the normal at which the filter has been operating for some time is attended by a marked increase in the number of bacteria in the effluent for periods of from several hours to several days, and this increase in number usually follows the change of rate in about such a time as to suggest that the multiplication of bacteria in the effluent is due largely to their detachment from the sand grains near the surface of

the filter. A comparatively sudden increase of rate from below the normal to the normal rate, as in intermittent filters, is not, as a rule, in filters of considerable age followed by a diminution of efficiency. Violent changes should at all times be avoided because they may result in disturbing mechanically the filtering materials, and consequently directly affect the efficiency of the process.

Influence of the Age of Slow Filters on their Bacterial Efficiency.—When a new filter is first placed in operation it does not at once begin to yield pure water. It generally requires from one to two months to establish its proper biological construction and give an effluent containing a low number of bacteria. This biological construction consists principally in the accumulation of organic and mineral matter, in a gelatinous film, around the sand grains, and in the development of the nitrifying organisms by which the organic matter and the bacteria are retained and destroyed. This power of retaining and destroying the bacteria in the applied water increases with the length of time the filter has been in operation. This increased bacterial efficiency, caused by greater length of service, is much more apparent in filters of coarse sand than in those constructed with fine sand, and, indeed, as filters of coarse sand increase in age, they resemble, both in bacterial efficiency and in ability to pass given quantities of water, filters of fine sand. This is probably due, on the authority of the Massachusetts State Board of Health, to the more closely compacted condition of the sand, caused

by a readjustment of the sand grains in refilling the filters from below, by the washing in of fine sediment, and the retention of masses of organic and mineral matter on the sand grains, which in reality reduce the effective size of the sand.

Influence of Scraping on the Bacterial Efficiency of Slow Sand-filters.—The theory had, until recently, been held in Europe that the effectiveness of the operation of slow sand-filters depended upon the formation of a layer of sediment upon the surface, by which the bacteria were retained. This theory was formulated upon the studies of the Berlin filters in 1887 by Piefke, Pflugge and Proskauer, and was quite generally endorsed by the majority of writers on the subject. At the present time, however, it may be said that most of the prominent engineers of Europe look upon bacterial action as the principal factor. Piefke,* of Berlin, contends that clay particles play an important part in the formation of the surface film, asserting that as the result of experiments he found such a film to be more efficacious than a film composed largely of bacteria and algæ. The most weighty proof that such a film is not indispensable is advanced by the Massachusetts State Board of Health in the four following propositions:

1. This film is not necessary in intermittent filters, which yield as high results, apparently, when this layer is cracked and peeled off by the action of the direct rays of the sun.

* Aphorism über Wasserversorgung vom hygienisch technischen Standpunkt ausbeobachted, Zeitschrift für Hygiene, 1889.

2. In the studies of continuous filters of fine or medium sand it has been observed that in more than 100 instances it was possible to remove from .10 to .30 inch in depth of the upper layer of the filter without causing a diminution of efficiency.

3. It has been observed that certain filters of coarse sand did not give normal bacterial results during the first months of their operation, even when the surface coating was thick enough to completely clog the filters, and yet after longer service their efficiency increased to the normal.

4. Chemical analyses of the sand taken from filters at different depths below the surface showed an accumulation of organic matter, it being, in some cases, 50 per cent. of that at the clogged surface at the depth of 3 inches.

Reinisch has also stated, from his studies of the Altona filters, that too much significance has heretofore been given to the surface coating.

The studies made at the Lawrence Experiment Station indicate quite decisively that the removal of the surface layer to the depth of an inch has but a very slight influence upon the bacterial efficiency, in the filtration of the Merrimac water, and that the effects of such deep scraping may often be disguised by other considerations. With depths of more than an inch the effect upon the bacterial contents of the effluent at Lawrence was generally very marked.

Raking over the surface to the depth of an inch, as compared with scraping, has not shown, under the conditions prevalent at Lawrence, equally good re-

sults. A disturbance of the sand to greater depths than this invariably results in reduced efficiency and long delays in the re-establishment of normal action. The ill-effects of scraping were more apparent in shallow filters than in those having deep sand layers. This fact suggests that the steadying effect of deep filters is a great safeguard when the plant is to be operated by unskilled labor, especially during the winter, when ice is apt to form, and when shallow filters would require the most intelligent and careful manipulation to yield satisfactory results.

The most satisfactory method of cleaning slow filters, as evolved both from American and European experience, is to scrape off the top surface to a depth of about one half to three quarters of an inch and then rake it over carefully and lightly to remove the marks of the boots of the workmen. This process is repeated, when necessary, until the sand layer is reduced to the minimum thickness allowed. The refilling with washed sand immediately after each scraping does not yield satisfactory results, as it generally produces sub-surface clogging at the junction of the new and old sand.

Effect of the Method of Application of Water to Intermittent Filters.—To obtain high efficiency in intermittent filters the water must be applied in such a manner as to avoid disturbing the surface of the sand layer. When the water is flooded over the top of the filter the air held in the body of the sand is forced to escape, and if its only outlet is through the surface there results a breaking of the continuity of the fil-

ter and reduced efficiency. If, however, the air is forced downward, and out through the underdrains, these ill-effects are very largely obviated.

Effect on Bacterial Efficiency of Method of Putting Slow Sand-filters in Use after Scraping.—The usual practice of filling filters after scraping has been to allow filtered water to slowly flow back into the underdrain of the filter and gradually rise above the surface of the sand. In some of the European filters it has been the custom to waste the first water passing through after a scraping, varying the quantity wasted according to circumstances. It has been found, however, that in nearly all cases satisfactory results can be obtained by filling from below, allowing the water to stand a short while before placing the filter in operation, and then starting filtration at a rate below normal. In this manner it is found that a sufficiently good effluent can be obtained, in many cases, without wasting. With waters low in the materials necessary for the production of the gelatinous film on the sand grains, less favorable results are obtainable by this method of starting; in such cases wasting may be necessary.

Effect of Temperature on the Efficiency of Slow Sand-filtration.—Observations at many filtration-works indicate that the reductions of bacterial efficiency which have been noted in extremely cold weather have been due to causes which could be removed by structural and operative changes; the low temperature of the water not being chargeable with the reduction of efficiency. Open filters which have shown low

efficiency in cold weather have, upon their being covered over to protect them from the formation of ice, shown again their normal power of removing bacteria. This has happened at Zurich, Berlin, and Koenigsberg. The filters at Altona and Hamburg and all the cities of England and Holland are open, and but little trouble has been experienced at these plants during winter weather. Where the winter temperature is such that many days of severe cold may follow in succession, producing several inches, or feet, of ice, it will generally be economical to cover the filters. This subject is discussed more fully on page 120. The reduction of efficiency in the winter months may be due to the disturbance of the top surface of the sand during the removal of ice; to the freezing of the surface after scraping; or to the necessity of compelling certain portions of the filters to be cleaned more frequently than the remainder of the area, resulting also, perhaps, in abnormally high rates of filtration on the parts so cleaned.

Conclusions.—From a careful consideration of the observed facts it is seen that, under favorable conditions, the process of slow sand-filtration may be very efficient for the treatment of polluted waters. It is also seen that some waters cannot be successfully treated by this process. The process is not efficient for the removal of coloring matter dissolved from leaves, roots and grass, peat and decaying organic matter. It is not efficient for the removal of turbidity caused by clay in a very finely comminuted condition; it is not efficient in improving the chemi-

cal quality of the water; and it is not efficient in the treatment of waters deficient in the organic matters necessary for the formation of the gelatinous film around the grains of sand. Further, continuous slow sand-filtration is not capable of purifying a water highly polluted with sewage and at the same time low in dissolved oxygen. For such waters intermittent filtration, or double filtration, may be necessary. In point of efficiency in the removal of bacteria from polluted waters, under proper conditions, however, this method of filtration takes first rank for reliability over all other practicable processes known to-day. It has passed the experimental stage, as a process, and is known, when properly applied under suitable conditions, to be safe, satisfactory and economical.

CHAPTER IV.

DESIGN, CONSTRUCTION AND OPERATION OF SLOW SAND-FILTERS.

DESIGNING.

Per Capita Water Consumption.—The number of filter-beds required to supply filtered water to a given population, and the size of each bed, depend principally upon the per capita daily water consumption, and upon the character of the raw water.

The per capita daily water consumption of the cities of the United States is generally higher in large than in small cities. This fact is one of the elements which makes the filtration of our large public supplies a matter of considerable expense, often influencing a city to defer improvements, in the hope that it may become, through more favorable conditions, better able to meet the expenditure at some time in the future. In filtration-works the annual cost of operation and the original outlay for construction are governed by this item, and, therefore, the necessity for avoiding needless waste is apparent when the purification of the water is contemplated. If a city of 100,000 people uses 15,000,000 gallons daily, requiring a filter-plant costing, say $450,000 for construc-

tion and about $43,000 per year for operation, could get along with 10,000,000 gallons per day, the works, at the same rate as above, could be built for $300,000 and could be operated for $29,000 a year. The difference is apparent. It is, however, the duty of the engineer to solve problems on a business basis rather than from a strictly theoretical point of view, and the question of waste restriction is one of the problems in which business enters to a very large extent. While no one will dispute the advantages of economy, public economists differ radically in the means proposed for bringing about their ends. In large cities with long-established customs, with peculiar industries, with special necessities for the use of water and special reasons why a large amount is wasted, reforms can only be made gradually, and, as it were, at the wish of the people. If a commission should, in such a city, order the immediate stoppage of all waste and insist upon the placing of meters on every consumer's supply-pipe, urging that nothing could be done in the way of purification of the water until such measures had been carried out, it would fail entirely in its mission, either as to reducing the waste or catering to the public interests by improving the water. While much can be done in the restriction of waste in cities, if the question is properly approached, it cannot be done in a day, and the difficulties of the task will increase with the magnitude of the city. The records of cities using meters show almost conclusively what can be done in this direction; but when it comes to inaugurating the introduc-

tion of these devices in large cities, where such action will affect realty investments, change the returns on productive property, and necessitate the expenditure of large sums of money for repairs and improvements to plumbing, there is sure to spring up opposition which can be overcome only with difficulty.

It is, therefore, better to look the matter squarely in the face. The most practicable policy is to proportion the works to suit the actual water consumption at the time. This will provide all the water the people have become accustomed to, and will avoid the semblance of a water famine which would ensue if the reduction of the supply were suddenly brought about. Then, after the works are built, is the time to begin lessons in waste reduction. By first metering willing consumers, of whom there are always a great many in large cities, the doubtful become convinced of the benefits of the system, and finally enough meter-takers can be secured to force into line those who oppose meters from ulterior motives. By such a procedure the consumption can be gradually cut down, and thus, as the city grows, the reduction in per capita consumption will permit the original works to serve, perhaps, for many years before extensions become necessary. This policy is not wasteful of public funds, and is possible of enforcement in many cases. The attempt to cram meters down the throats of an unwilling public, willy-nilly, is generally productive of a species of mal-de-meter, so to speak, that becomes endemic and difficult to eradicate; the prevailing symptoms being a feverish excitement in councils, a

chilly reception of the measure by the press, followed by a feeling of intense depression on the part of the friends of the meter.

The small per capita water consumption of some of the large European cities is often quoted as proof that our cities are extravagantly wasteful of water, but to any one who has spent considerable time in these cities, not in the fine hotels where rich Americans congregate to be fleeced, but in the homes of the middle classes and in the smaller hotels, the reason for the small consumption will be apparent on starting a search for a bath-tub or water-closet. They do not waste water; they do not use enough of it, from the American point of view. Manchester, a few years ago, was one of the favorite cases held up to wasteful American cities as an example of what could be done in the matter of getting along without water; she is no longer useful for that purpose, because since the building of the sewers and the introduction of water-closets, wash-stands and stationary tubs, and numerous other conveniences that are to be found in every American hamlet of 3,000 people, the consumption is gradually climbing up to where it ought to be, judging from the American standpoint. It is neither practicable nor desirable to attempt to limit the use of water in our large cities to such low figures as are quoted for some of the foreign cities, as we have different conditions of national temperament and municipal and governmental administration. A great deal can be done,

however, in the detection of useless waste, by inspection, or other means, and offenders should be brought in line, so as to keep the consumption down to the lowest practicable limit, in order to save expense in construction and in the operation of the works.

Number of Filter-beds Required, and Excess Area to Be Provided.—Having decided upon the per capita water consumption, the most advisable rate of filtration, in consideration of the character of the water and the sand, the proportioning of the number of beds and the size of each depends upon the amount of area that must be provided in excess, to permit of the periodical cleaning of the beds. This excess area varies greatly in the extant works, ranging from 5 per cent. to about 20 per cent. of the total area, and in some of the smaller ones being 100 per cent. It is not necessary, usually, to proportion the works for a much larger population than is resident in the city when they are completed, because the plant will be capable of extension at a cost probably not much higher in rate than the cost of the original works, with the possibility of deferring extensions if it is feasible to reduce the waste in the city.

For waters carrying a good deal of suspended matter, or particularly rich in algæ growth, the required proportion of excess area will be greater than for clear waters, because in the former cases the beds will require frequent cleaning; under such conditions, with proper preliminary treatment by sedi-

mentation or other methods of clarification, it is seldom that the beds will require cleaning oftener than once a week, when operating at ordinary rates; while with clear waters it is seldom that the beds will require cleaning as often as once in two weeks. In most of the existing works the average period between cleanings is about a month.

After deciding upon the allowable maximum rate of filtration, the proper size and number of beds may be determined when the maximum daily draft on the filters is known. The water consumption will fluctuate with the time of day, with the days of the week, and the seasons of the year. The maximum to be expected should not exceed the average daily draft by more than from 50 to 60 per cent., and, therefore, unless there are storage reservoirs of ample capacity in the distribution system, the beds should be proportioned to deliver in 24 hours 1.5 to 1.6 times the average daily draft, in order that the maximum rate of filtration may not be exceeded. A reservoir sufficiently large to balance the hourly fluctuations in draft should also be provided. A discussion of the proper amount of storage to meet this requirement will be found in chapter VIII.

If the distribution or storage reservoirs are large enough to balance the daily fluctuations of draft, the beds may, of course, be designed for average draft instead of maximum.

As has already been discussed on pp. 93 to 96, the increase, within reasonable determinate limits, of the rate of filtration of slow sand-filters operating nor-

mally at fairly slow rates may occasionally be permissible for short periods of time, depending upon the relative pollution of the water, and other factors. Advantage may sometimes be taken of this to design the filters for the average draft of water, providing a small filtered-water reservoir to balance the sudden changes in rate of draft, and depending upon the flexibility of the filters to meet the daily or seasonal variations.

The total necessary effective area for the filter-beds, including the surplus area, to be provided to permit of the periodical cleaning of the filters as they become clogged and still not work the remaining beds beyond the prescribed limits, may be found from the following formula:

$$A = \frac{Q}{r}\left(1 + \frac{1 + \frac{cn^*}{p+c}}{n - 1 - \frac{cn^*}{p+c}} \right)$$

A = total necessary area, including reserve, in acres.
Q = total quantity of water to be filtered daily in million gallons.
r = rate of filtration in million gallons per acre per day.
n = number of filter-beds, including reserve beds.

* The expression $\frac{cn}{p+c}$ will generally be fractional, but in the formula use the nearest integer as follows: If the expression equals or is less than 1, 2, 3, 4, etc., take as its value in the formula 0, 1, 2, 3 etc., respectively. If it is greater than 1, 2, 3, 4, etc., take as its value 1, 2, 3, 4, etc., respectively.

p = ordinary minimum number of days of service between cleaning.

c = number of days each filter is out of service while draining, cleaning, and refilling.

The following illustrations will serve to show the relative effects on the size of the beds, of different assumptions regarding the operation of the works, and will point out the economies which may be effected in designing and operating a plant.

Suppose a city uses 100,000,000 gallons of water daily, and the filters are to operate at the maximum rate of 5,000,000 gallons per acre daily. The plant consists of 20 beds, the average period between cleanings is six days, and each filter is out of service three days for cleaning, resting, and refilling.

1. The area of each bed would be 1.5461 acres, requiring a total area of 30.92 acres.

2. If the lapse of time between cleanings were thirty days the area of each bed would be 1.111 acres, and the total area 22.22 acres.

3. If in the first instance the beds were out of service only two days instead of three, the area of each would be 1.33 acre, and the total area 26.6 acres.

In the second case the beds were designed for monthly cleanings, and 2 beds would be in cleaning, while 18 would be in service. If now a period of bad water were to come on, and the beds required cleaning every six days, it would be necessary to have 7 beds in cleaning, and 13 beds, with an area of 14.55 acres only, would be in service. For these 13 beds to deliver the requisite 100,000,000 gallons

daily the rate of filtration would have to be increased to about 6.92 million gallons per acre per day, or to a rate about 38 per cent. above the normal rate. The effect of changing the rate by this amount might not be so dangerous as to preclude its occasional occurrence if special precautions were taken during these periods to insure as great efficiency as possible. It would, therefore, under the conditions assumed, not be economical to proportion the beds upon the basis of weekly cleanings, as that assumption would necessarily increase the cost of the plant by about 60 per cent. On the other hand, no economy would result, in this case, in designing the beds for a period of as long as forty-five days between scrapings, because there would still be 2 beds in cleaning, and the proportion of reserve area would be the same, unless the number of beds were less than 17.

Now as to the effect of changing the number of beds, still assuming the same quantities for consumption, rate of filtration, a thirty-day period between scrapings and three-day periods of rest:

Supposing 11 beds were built; the area of each would be 2 acres, and the total area 22 acres, thus requiring 0.22 acre less than if 20 beds had been built. Assuming that the cost of filtering materials, roofing and flooring are the same per square foot of area for filters of all sizes, an assumption not far from the truth, there would be a saving, in using 11 beds, of 9 division walls between filters, 9 inlet wells with regulating apparatus, 9 outlet wells, 0.22 acre of fil-

tering materials, roofing and flooring, and a small saving in the cost of underdrainage.

The increased cost and disadvantages, from the use of 11 beds, would result from a slightly greater inconvenience in handling the sand in scraping and refilling; and, in open filters, where ice of considerable thickness is apt to form, additional difficulties in scraping, and in disposing of the ice.

It is evident, however, that economy of construction favors large beds. In any case it is necessary to decide, first, the maximum rate of filtration to be allowed and then to determine the corresponding number of beds, regard being had to the period between scrapings that will make the total area the least while insuring that the allowable maximum rate on the beds in use will not be much exceeded if the period between scrapings is occasionally reduced to six days. The maximum practicable size for filter-beds has not been definitely determined. The largest in use are the uncovered beds at Hamburg, which have an area of 1.88 acre each, and have given satisfactory results. Most of the beds of the other European filters are from .5 to 1.5 acres in area each. Frequently local prices of land, of labor and of materials may have an important influence in deciding the size of the beds. It would hardly be necessary in any case to make the beds larger in area than 2 acres each, as even in very large plants no great economy would result from using larger sizes.

In the examples which have just been discussed,

if the maximum rate had been fixed at 7.5 million gallons per acre daily, it would have been found more economical to use 16 beds and a period of service of forty-five days between scrapings. In this case the 15 beds in service would ordinarily deliver the prescribed quantity at the rate of 5,000,000 gallons per acre daily, and the total area required would have been 21.33 acres; 0.89 acre less than with 20 beds designed for thirty-day periods, and 0.66 acre less than for 11 beds also designed for thirty-day periods. If a different length of time is assumed for the filter to be out of service the resulting proportion of reserve area will also be slightly changed.

Location and Grouping of Beds.—After having determined the proper area and number of beds, the grouping of the beds into an economical design will be influenced by the shape of the available tract of land, its topographical features, and the judgment of the designer. The points to be borne in mind are: A sufficient area must be reserved for the washing and storing of the sand during cold weather, when washing would be attended with considerable difficulty and expense; and, in case the beds are not covered, for sufficient space for storing ice cut to permit cleaning; to allow of sufficient room for the location of the various pipes below the ground, and the tramways above the ground for the handling of the materials; for the convenient placing of the filters relative to the sand-court so as to make the average distance that the sand must be conveyed as short as

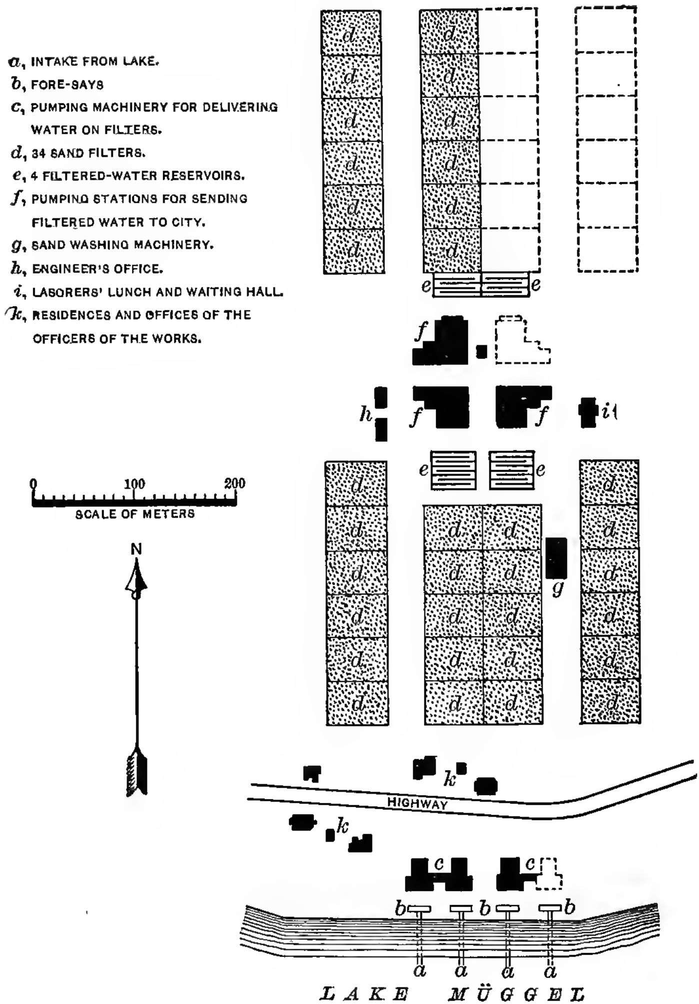

FIG. 5.—ARRANGEMENT OF THE LAKE MÜGGEL FILTER PLANT, BERLIN, GERMANY.

possible, and the proper placing of the clear-water reservoir relative to the filters so as to make the length of piping a minimum. The arrangement of the Lake Müggel works at Berlin is shown in Fig. 5.

Shape of Filter-beds.—Filters are usually made rectangular in plan when the topography of the land does not require some other shape. Circular or polygonal shapes are rarely used when the rectangular shape is possible, although in very small covered filters the circular form is quite advantageous. The principal arguments for the circular shape are that with it the cost of surrounding walls is a minimum for a given area, and the area of contact between the side-walls and the sand is a minimum, thus reducing the danger of unfiltered water passing down between the sand and walls also to a minimum. A typical plan of one of the Berlin filters (Lake Müggel) is shown in Fig. 6. The most economical shape for a rectangular filter-basin, if not subdivided, is the square. If divided into several basins the economical dimensions may be obtained from the following formulas, in which it is assumed that the dividing walls cost about the same per foot run as the side-walls.

If the basins are all in one row, side by side, the length of the short side, $x = \frac{n+1}{2n} y$, in which y is the length of the long side and n the number of filters. If the filters are placed in two rows, back to back, and side by side, in the row, the formula be-

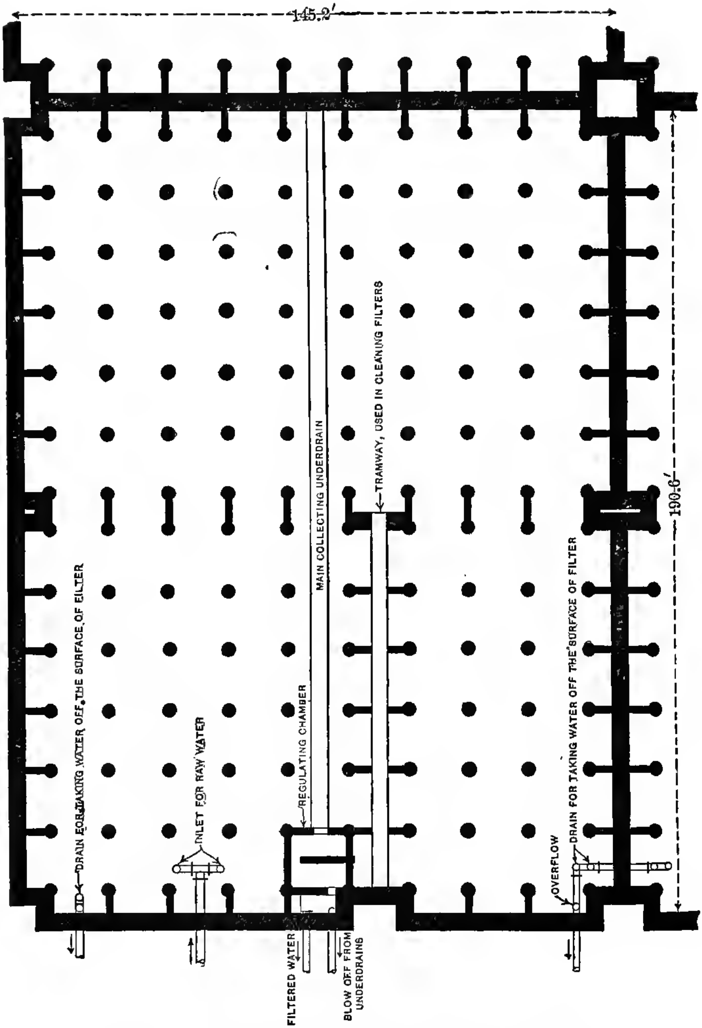

FIG. 6.—PLAN OF BERLIN (MÜGGEL) FILTER-BED.

comes, $x = \frac{2(n+2)}{3n}$, if there are the same number of beds in each row.

Depth of Filters.—The depth should be sufficient to provide for the filtering materials and the superincumbent water; it will generally be about 10 feet, varying a foot or two each way from this in special cases, depending upon the fineness of the filter-sand, the character of the water and the economies of design.

CONSTRUCTION.

Preparation of Site.—Where the ground-water level is higher than the bottoms of the proposed filters, the site should be drained by a system of pipes, laid with open joints, and surrounded with gravel, so that after the filters are completed there can be no upward pressure on their bottoms. The drains should discharge at an outfall, or into a sump, or well, from which the water may be pumped. The site of the Hamburg filters is underdrained in this way, the sub-soil water being pumped from a well and discharged into the river.

Side Slopes and Bottoms.—Open filters are frequently built with sloping side-walls, formed in excavation or by embankment, rather than with vertical retaining walls. The side slopes are usually 1 to 2 or 1 to 3, and are protected in various ways. Generally a layer of well-packed clay provides for water-tightness, the surface being protected by a paving of brick, stone, or concrete. The Hamburg

filters are excavated with side slopes of 1 to 2. The bottoms and slopes are covered with puddled clay. The bottom is paved with a floor of bricks laid on their sides, and the slopes with bricks set on edge; in both cases laid in cement mortar. In using this method of lining very hard impervious bricks are desirable. In the zone where there is danger of ice forming and adhering to the sides, every precaution should be taken to make the paving impervious and able to resist frost and abrasion. Open beds with sloping side-walls present the advantage that they are not so apt to be damaged with frost and ice as are those with vertical walls. The beds with sloping sides are said, however, to be the more difficult to keep water-tight. All square corners should be avoided in the construction of beds with sloping side-walls, as there is great danger of the formation of cracks along the angles, which would allow the water to percolate to the underdrains without being properly filtered. The relative costs of open beds with sloping and those with vertical side-walls will depend upon circumstances. Usually beds with sloping sides will be the cheaper, but if land is very expensive it might be possible that those with vertical walls would be preferable.

When the ground upon which the filters are to be built is compressible and yielding, many difficulties may be encountered in holding the excavation and the walls. In such cases foundation piles under the walls and piers, and sheet piles around the edges of the excavation, or, perhaps, the construction of the

side-walls in trenches, followed by the excavation of the interior space, or the dividing of the excavation into different sections may be necessary.

Precautions to Prevent Water Passing to the Underdrains in an Unfiltered State.—The greatest care should be taken to secure perfectly water-tight workmanship, so that there may be no possibility of unfiltered ground-water finding its way up through the bottom and into the underdrains.

Sharp salient and re-entrant angles of all piers, buttresses and side-walls should be rounded off to insure better contact between the sand and the masonry, to preclude the danger of the water following such angles to the bottom of the filter without being properly purified. In order to prevent the unfiltered water from creeping between the side-walls and sand it would be well, in concrete construction, to batter the walls, piers and buttresses, from the bottom to above the level of the filtering materials, so that the settling of the sand under the action of the water would tend to make the contact closer the longer the filter is in use. In the Albany filters Mr. Hazen introduced ledges around the faces of the walls and piers, below the surface of the sand, formed by steps or offsets in the brick work. Mr. Rudolph Hering has suggested the sanding of the concrete surface before the mortar has set.

Effects of Hot Sun on Open Filters.—Serious leaks due to cracking of the underlying clay-puddle are apt to occur in open beds, when they are exposed to the hot sun for several days with the water drawn off

and the filtering materials removed. Under such conditions there may also occur a buckling of the floor and side-walls, or a formation of cracks, resulting in decreased efficiency of the filters. These dangers are entirely avoided by covering over the beds with a roof, carried on piers, and overlaid with a few feet of earth. In cold climates this covering is doubly necessary to prevent the formation of ice of considerable thickness upon the surface of the water, the removal of which, by disturbing the top of the sand and by pre-requiring the greater part of the water to be filtered upon the limited area that can be kept properly scraped, may reduce the efficiency very greatly.

Covering Filters.—It cannot be said that there are any advantages to be gained from covering filters, excepting to avoid the difficulties inherent to keeping the filters operating properly during cold weather, and to prevent the growths of algæ, which produce rapid surface clogging on the filters in summer weather. To prevent the latter trouble, a light, inexpensive trussed roof would suffice, as its only object would be to exclude light. Covered and uncovered filters, other things being equal, yield equally good results, when properly operated.

Open filters are more easily cleaned than those with covers, and have the advantage of presenting an unbroken surface for the filtration of the water. Covered filters have many columns, piers, buttresses, etc., which pass through the filtering materials, and around which it is difficult to place the sand with the

same degree of compactness as in other portions of the filter. On account of the space taken up by these piers and buttresses additional area is required to compensate therefor. It is also said that for some kinds of water it is difficult to secure sufficient ventilation in covered filters during summer. This, however, seems to be a small point.

Generally speaking, therefore, covering will be necessary in climates where long periods of severe cold are likely to occur in the winter, or where algæ growths would seriously interfere with the economic operation of the plant in the summer. In cities where the question becomes an economic one, a study should be made of the number of successive days of freezing weather, the degree of cold during these spells and the lengths of the periods of intervening thaws. The formation of ice on the water will not, *per se,* affect the efficiency of filtration. If the ice does not last longer than the period during which the filters can be safely operated between cleanings, it need not be considered as a factor in the question of providing covers. Since covered filters cost from 50 to 100 per cent. more than the open type, it may, in some cases, be cheaper to provide more area of open filters than to cover those actually required, if by that means the plant can be operated a sufficiently long time to allow the ice to melt or be safely removed from part of the area before scrapings are necessary. In rather mild climates a trussed roof, similar to that over the Koenigsberg filters, might afford sufficient protection, or some of the beds

might be covered and some left uncovered, as at Stralsunder.

Another combination which might be advantageous in climates where ice would give trouble, would be to provide a certain proportion of the required filter capacity in open slow filters, and the remainder in rapid filters with a comparatively low rate, say 100,000,000 gallons per acre per day. Then during very cold weather the slow filters could be operated

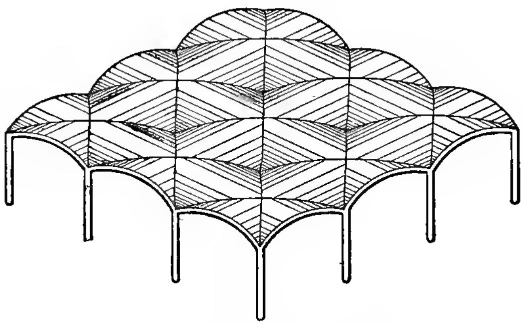

FIG. 7.—GROINED ARCHES.

at a slow rate, perhaps half of the summer rate, so as to postpone the times of scrapings, and the rapid filters could be operated somewhat more rapidl than at the summer rate. This presupposes that the water is of a character to be successfully treated with rapid filters. The flexibility of rapid filters, within pretty wide limits, as noted in chapter III., makes such a combination as this quite practical, and in some cases may permit the building of open slow sand-filters, the whole plant being very much less

expensive than one consisting entirely of covered slow sand-filters, while at the same time being equally efficient. During the winter time, the relative pollution of most streams is lower than in summer, because the polluting matter is retained longer on the surface of the ground, and the stream flow is also

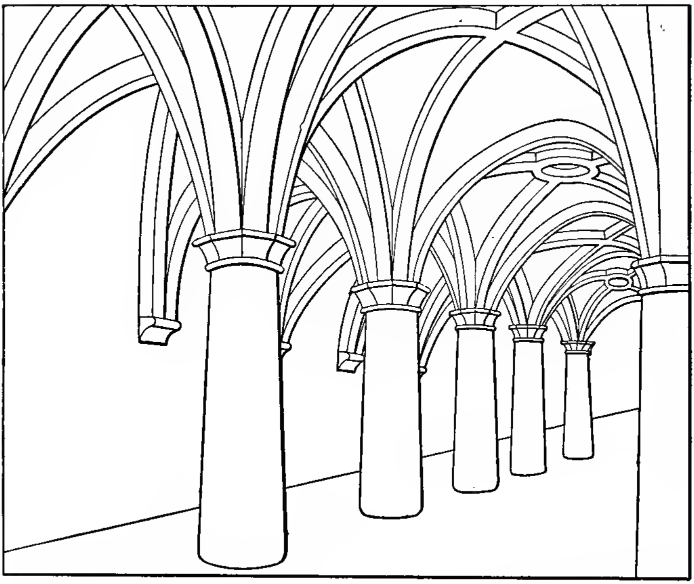

FIG. 8.—MASONRY GROINED ARCHES WITH ARCH RIBS.

generally greater than during the summer months. Thus in the summer the main reliance would be upon the slow sand-filters, and during the winter upon the rapid sand-filters.

In very cold climates the cost of removing the ice is a significant part of the cost of operation of open

filters. The tendency in the German works is toward covered filters, while in England and Holland the filters are almost without exception uncovered.

Groined arches (Fig. 7, 8 and 9), springing from the tops of columns, are generally used for covering filter-beds, because of the ease with which they may

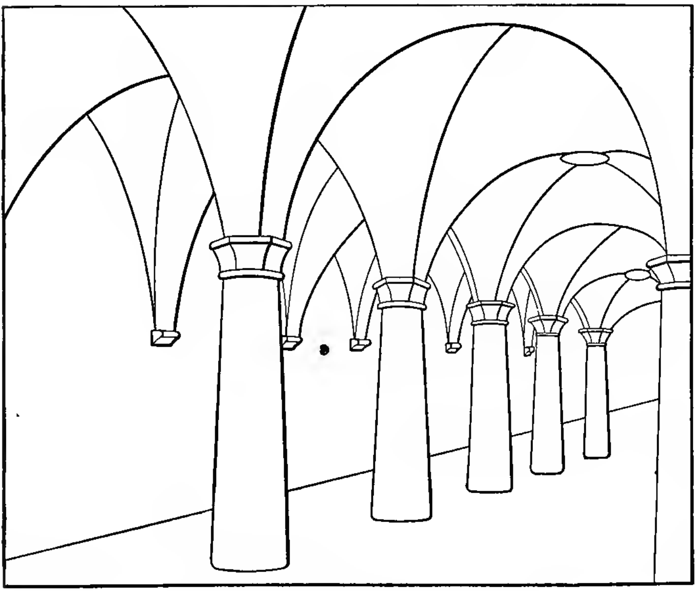

FIG. 9.—CONCRETE GROINED ARCHES.

be constructed of brick masonry or concrete. An interior view of the Ashland, Wis., covered slow sand-filter plant, designed by Wm. Wheeler, C.E., is given in Plate V. The roof over this filter is the first application in the United States of groined arch construction for a filter cover.

PLATE V.—INTERIOR VIEW OF ASHLAND, WIS., COVERED FILTERS. FIRST ADAPTATION IN THE UNITED STATES OF THE GROINED ARCH AS A FILTER ROOF.

The average thickness of the groined concrete arches covering the Albany filters is about 7 inches, the thickness at the crown being 6 inches.

The new Berlin filters have covers of a unique design. The roof is a series of domes, supported on piers (Figs. 8 and 10). The domes were constructed

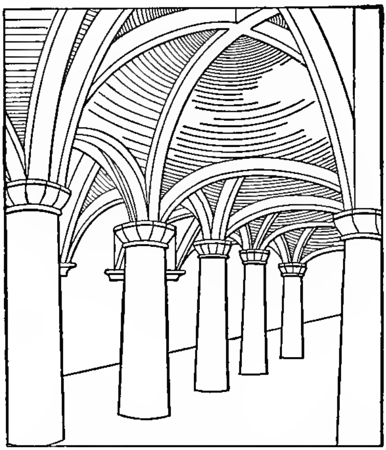

FIG. 10.—DOMED COVERING WITH ARCH RIBS.

by springing arch rings from the tops of the piers, on the sides and diagonals of each panel, and then filling in the space between the rings with the shell of a dome, the brick being put in place by hand, without the use of centres. The work is beautifully done and is very effective, although much more expensive than concrete groined arches would have been. They have a way of doing things in Europe, particularly in Germany, in the building of public works, which might well be emulated by American

cities, to a certain extent, at least. In our average American town the policy is usually to be over-ornate in structures showing above ground, and to be over-economical in the execution of works which are out of sight. Very often, however, this policy is not truly economical. In works pertaining to public sanitation nothing can be too good that will conduce to the greater care and attention which attractive sur-

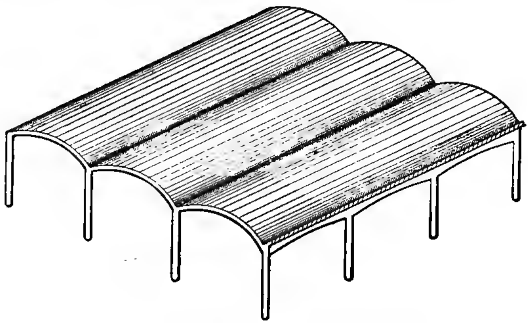

FIG. 11.—CYLINDRICAL ARCHES.

roundings will naturally beget. Nothing is more conducive to good maintenance than appropriate construction and well-built structures. For this reason, in filter plants, the effort should be made to have the interior finish of the walls, piers and arches properly carried out, and the gate-houses, entrances and other works above ground architecturally presentable. Few engineers are skilful enough designers to be trusted with the treatment of the architectural features. The countless monstrosities in the shape of pumping stations, etc., that are to be seen in our large cities bear witness to the folly of entrusting

such designs to men educated highly, no doubt, in the uses for which the structures are built, but incompetent architecturally and artistically.

Domed constructions, cylindrical arches (Fig. 11) or composite roofs of steel and concrete may be used instead of groined arches, if desirable. An economical form of roof is one composed of flat domes resting on the tops of piers (Figs. 12 and 13) similar

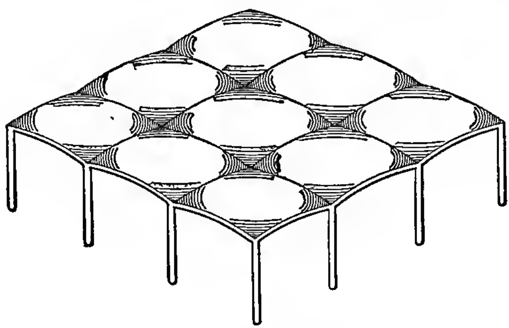

FIG. 12.—FLAT DOMES.

to the Berlin roof, above described, but made of concrete and expanded metal. The cost of making the centering for this form is a trifle more than for groined arches, but the saving in concrete is very considerable. A view of the centering for the groined arches forming the roof of the Somersworth, N. H., filter is given in Plate VI.

By the use of the domed construction with expanded metal, properly placed, the average thickness can be reduced considerably below that required for groined arches. The author has built a circular reservoir for spring water, now in service, covered

with a concrete and expanded-metal dome, of a span of 16 feet, rise of 2 feet, and average thickness of 5 inches, with a covering of 2 feet of earth. The earth covering was dumped on it from wagons. He has also built two other domes, in a similar manner, having spans of 20 feet, rise of 3 feet and average thickness of 5 inches.

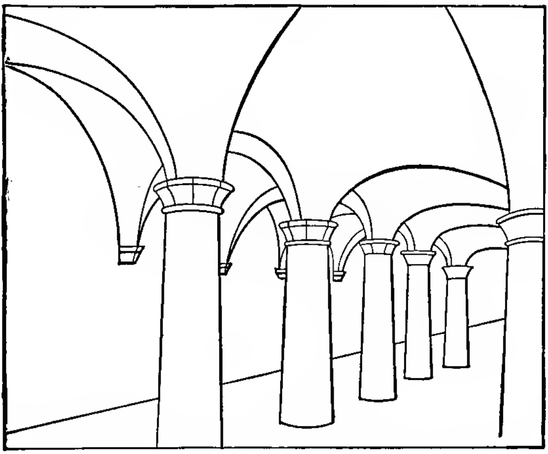

FIG. 13.—CONCRETE DOMED CONSTRUCTION.

Drainage of Roof.—The water falling on the roofs of filters may be allowed to drain into the filters through the roof, in pipes carried down through the piers and discharging above the level of the sand. The top ends of these drains should be covered in some way so as to prevent the entrance of dirt, and should provide free exit for the water, so as to prevent injury to the work by the action of frost.

The roof should be covered with coarse sand, or

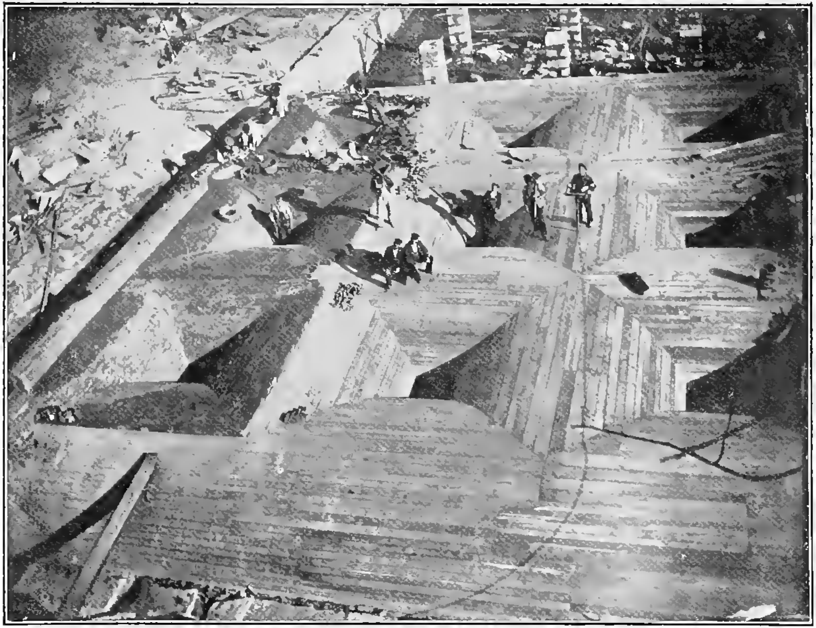

Plate VI.—Somersworth, N. H., Covered Filters. Bird's-eye View of Centering for Groined Arches.

gravel, to facilitate drainage, and on top of the gravel about two or three feet of earth should be spread to keep out the cold. The top six inches of filling should be top-soil, which should be fertilized and seeded with grass, while the slopes of terraces or banks should be sodded. The treatment of the tops of covered filters offers opportunities for the display of taste in landscape work.

Ventilation.—Much more provision should be made for ventilation and lighting than is usual in reservoir construction, as the operations of cleaning and refilling filters will occur quite frequently and can only be done effectively in good light.

In the centre of alternate panels in the roof manholes should be built to provide for ventilation and light. These should extend from the roof to the top of the earth covering, and should be about two feet in diameter at the top and slightly larger at the bottom. Each should be provided with a cover which could be removed if necessary. A convenient and satisfactory arrangement is to have a double cover, the lower one being wire-glass and the upper one of metal treated with a preservative coating.

In large plants it is desirable, if not always necessary, to install an electric-lighting plant, with arc lights for the sand-courts, roads, etc., and incandescent lights placed in the gate-houses, and distributed through the basins of covered filters.

There is no reason why the roof need be much above the highest water-level, though sufficient

head-room should be provided, of course, for the convenience of the workmen in cleaning. The actual height will depend upon the depth of water allowed upon the filter surface, the limiting filtration head and special features of the regulating apparatus and conduit leading to the filtered-water reservoir.

Tramways for Sand Haulage.—In nearly all the large slow sand-filter plants now in operation it is the general practice to provide tramways for transporting the sand removed from the beds to and from the sand washers. It will not be long, however, before some radical changes will be effected in the methods of cleaning slow sand-filters, having for their object the reducing of the amount of hand labor involved in the process as now practised. When tramways are used it is convenient to provide branches from the main tracks, one running into each covered filter and sloping down to the level of the sand surface, so that the cars can be taken in and out of the filters. The track should be supported between two rows of piers and extend generally to about the centre of the filter. Over the track the roof is usually a cylindrical arch, its axis sloping with the track so as to provide sufficient head-room.

For open filters portable tracks are used with success.

Bottoms.—Inverted groined arches, Fig. 14, make the best form of bottom for slow sand-filters, because this form is economical, furthers the proper distribution of the load on the columns carrying the roof, gives a strong section and provides valleys in which

Plate VII.—Somersworth, N. H., Covered Filters During Construction.

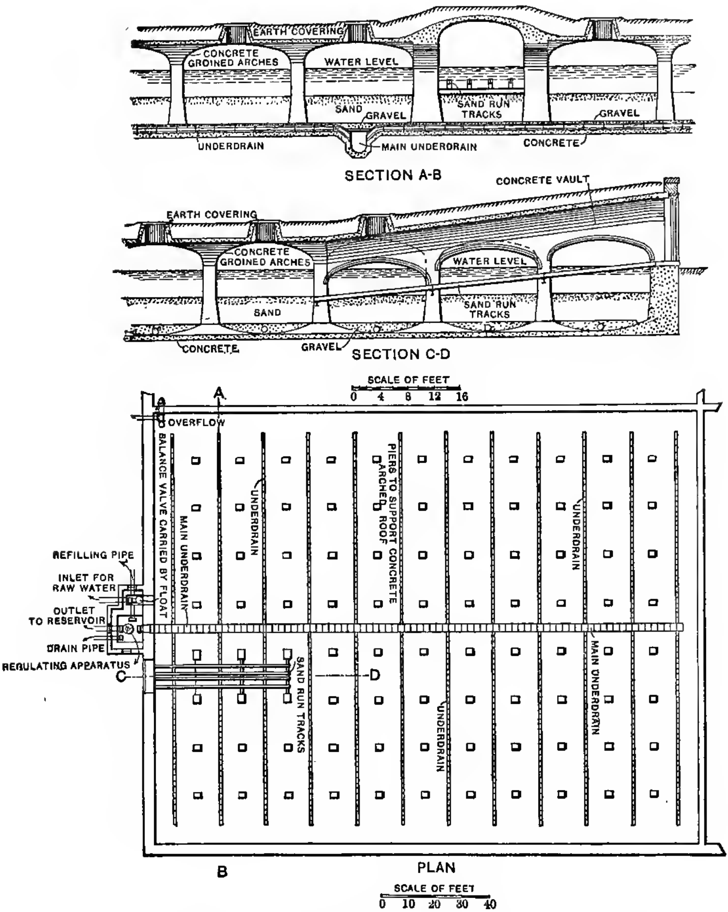

FIG. 14.—TYPICAL PLAN AND SECTIONS OF COVERED SLOW SAND-FILTER.

the underdrains may be laid. Slow sand-filter floors should never be horizontal planes, but should be broken into ridges and valleys inclining towards the underdrains so as to remove the water as

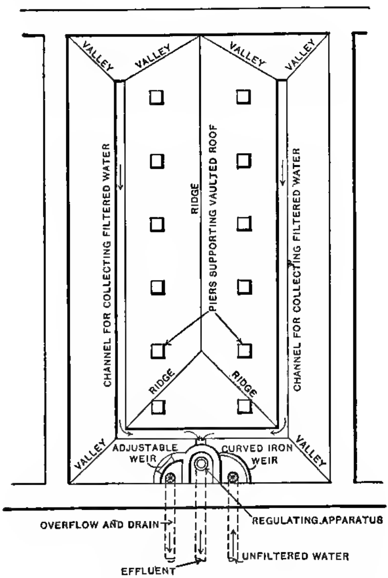

FIG. 15.—PLAN OF FILTER-BED, ZURICH, SWITZERLAND.

fast as it is filtered. The manner of accomplishing this in the Zurich filters is shown in Fig. 15. If allowed to stand in the gravel the water will gradually deteriorate in quality, to a greater or lesser degree. The best practice, in regard to the underdrains for collecting the water after it has passed through the sand and gravel, is to use small vitrified pipes for the lateral drains, placing them upon the

filter floor, and form the main collector in the concrete bottom of the filter. This main collector should have a semi-circular invert and straight vertical side-walls and should be covered with slabs of concrete or stone.

This method is better than using pipe, built into the concrete, for the main collector, because during the construction of the basins, mortar, dirt and other débris is likely to get into the main underdrain, and its cleaning later may be a difficult matter. With the open drain, however, the débris can be easily removed.

Underdrains.—The sizes of the underdrains depend upon the area of the bed, the distance between the collectors and the amount of water to be filtered in a given time. In proportioning the sizes, ample allowance should be made on the side of safety, so that the frictional resistances may not cause unequal rates of filtration in different parts of the beds. As the cost of the underdrains is a very insignificant part of the cost of filter-beds, it is bad practice to attempt to keep the sizes down to the danger limit, to save a few hundred dollars, at the risk of lessening the efficiency of the filters. I would suggest that if the sizes are proportioned so that the total frictional resistance, when filtering at the maximum rate, from the outlet to the most distant point is kept down to about .01 to .02 foot, no trouble will be experienced.

Great care should be taken in placing the underdrains, if of pipes, to leave enough space open at the

joints to permit the water to enter without requiring too great velocity head.

The conversion diagrams (Figs. 16, 17 and 18) will

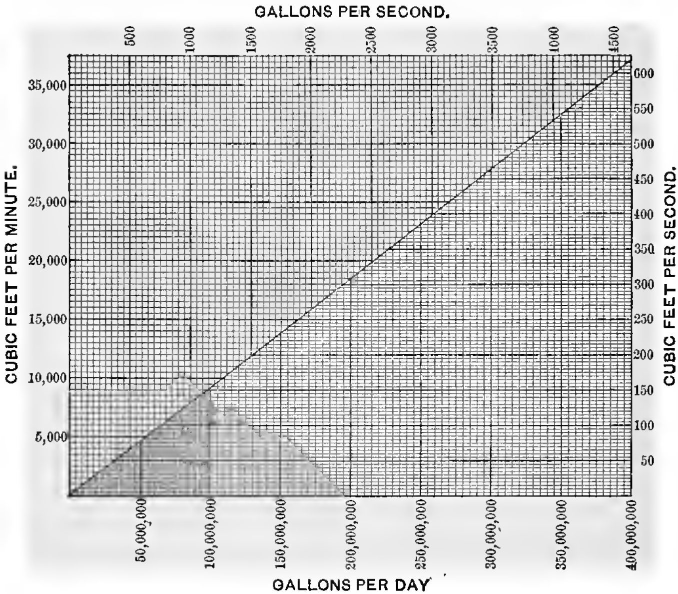

FIG. 16.—CONVERSION DIAGRAM.

Gallons per day into cubic feet per second and per minute, and gallons per second.

be of service in estimating the quantities of water that will be discharged by the underdrains and collectors.

For convenience in proportioning the sizes of pipe underdrains, Fig. 19, based on Kutter's Formula, with $n = .013$, has been prepared. Knowing the quantity of water to be filtered, and the allowable loss of head, the sizes and slopes can readily be found.

In place of using pipes for underdrains some works

have floors made of two layers of ordinary bricks, the bottom bricks resting on edge, a little distance

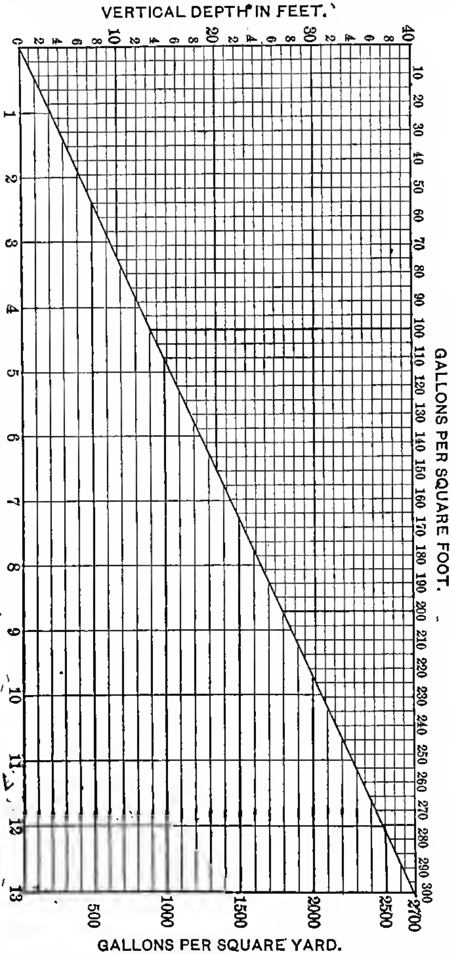

FIG. 17.—CONVERSION DIAGRAM.
Million gallons per acre into gallons per square yard, gallons per square foot, and vertical depth in feet.

apart, and the top layer lying flat upon them to form the floor for the filtering materials. In other places

special hollow bricks are used for the purpose. The form of bricks used at Zurich is shown in Fig. 20. There is no special advantage to be gained by this

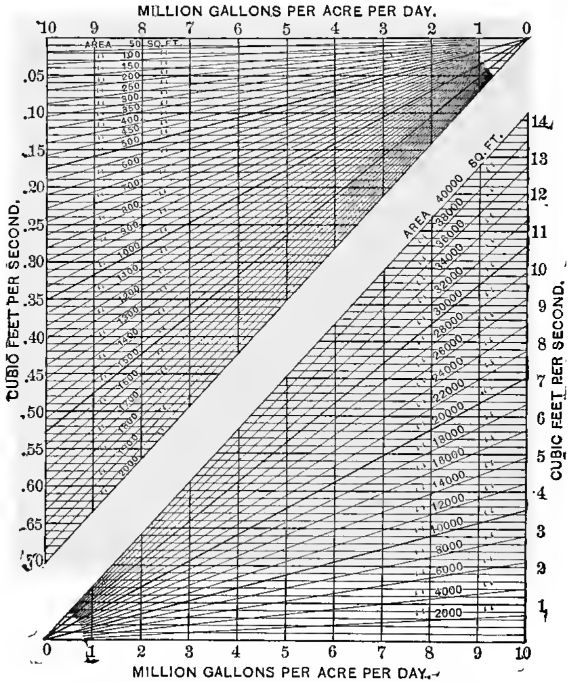

FIG. 18.—CONVERSION DIAGRAM.

Million gallons per acre per day for different areas into cubic feet per second.

form of construction, and its cost is considerably in excess of the more simple expedient of using vitrified pipes and properly graded and placed gravel layers.

Gravel Layers.—To provide free passage laterally to the underdrains it is the custom to cover the floor

with layers of gravel or broken stone of sufficient thickness to permit free passage of the water without consuming too much friction head. The resistance to

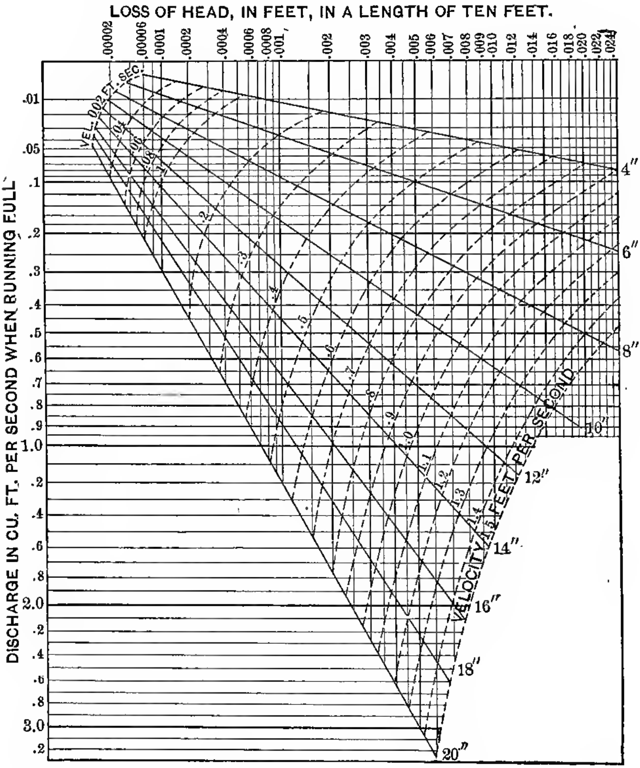

FIG. 19.—DIAGRAM SHOWING FRICTIONAL LOSS OF HEAD IN PIPES.

the motion of the water depends upon the size of the particles of the gravel, the rate at which the water is passed through the gravel, the temperature of the

water, and the thickness of the gravel layer. In Fig. 21 the data given in the report of the Massachusetts State Board of Health for 1892 are arranged in such a manner that the loss of head in a gravel layer one foot thick can be taken by inspection, for various sizes of gravel and distances that the water must

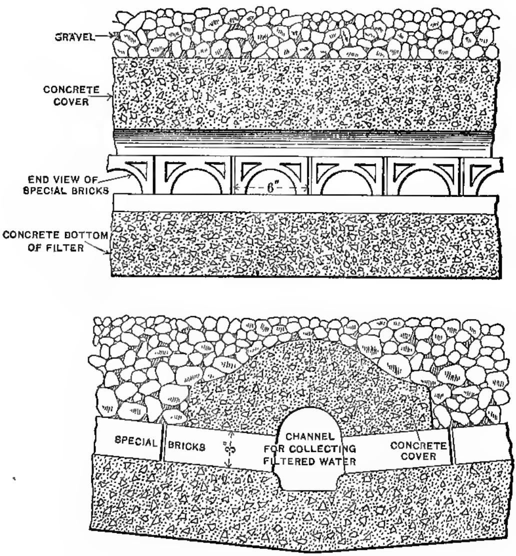

FIG. 20.—HOLLOW FLOOR, ZURICH FILTERS.

travel to reach the underdrains, for a rate of filtration of one million gallons per acre per day. For other thicknesses of gravel the rate will vary inversely as the thickness, and for other rates of filtration directly as the rate.

The gravel should be placed in the filters in continuous layers, the particles of each layer being a

little smaller than those of the layer below, to prevent the filtering sand from being washed into the drains. The coarse gravel, or broken stone, bed is to be considered only as serving the purpose of permitting the more or less free movement of the water to the underdrains. The superimposed thin layers of gravel of decreasing sizes are to support the sand

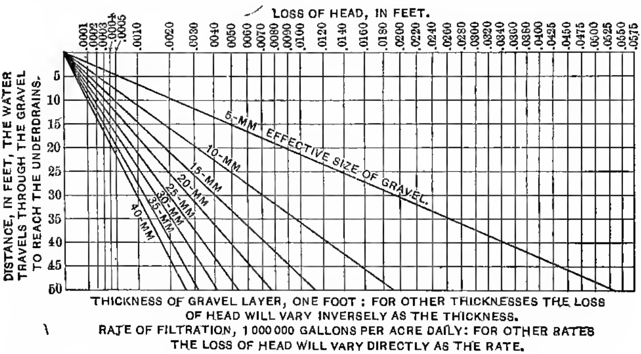

FIG. 21.—DIAGRAM SHOWING HEAD OF WATER CONSUMED IN PASSING HORIZONTALLY THROUGH GRAVEL LAYERS.

and prevent it from being carried into the underdrains by the sinking of the water.

These layers need not be thick, but they should be of screened gravel, and each layer should be continuous over the one below it. When properly placed and graded as to sizes, experience has shown that there is very little movement of the particles, and layers $1\frac{1}{4}$ to 2 inches thick, depending upon the size of the particles, have been found to be in perfect condition after several years of service. No difficulty will be experienced if care is taken that the particles

in each layer are not more than three or four times as large as the particles in the superimposed layer. An interior view of the Somersworth, N. H., slow sand-filters, taken when the underdrains and gravel layers were being placed in position, is given in Plate VIII.

The influence of the size of the particles and the thickness of the layers will be felt in the head used up in the passage of the water to the underdrains. The smaller the gravel and the thinner the layer the greater the head necessary to pass a given quantity of water in a given time. This may result, with poor designing, in the parts of the filters remote from the drains passing the water at a slower rate than parts over the drains, a condition which should be avoided as much as possible. Since the thickness of the gravel layer must be deeper the greater the distance between the underdrains, there can be found an economical depth of gravel when the size of its particles, its cost, the rate at which the water is to be delivered, and the allowable loss of head are known.

Filtering-sand.—The velocity with which water will pass through sand layers of different effective sizes, at different temperatures, and under different heads, has been the subject of experiment by the Massachusetts State Board of Health at different times. The first experiments were summarized in the report for 1892. These results were expressed by the formula:

$$v = cd^2\frac{h}{l}\left(\frac{t \text{ Fahr.} + 10^\circ}{60}\right).$$

PLATE VIII.—INTERIOR VIEW OF SOMERSWORTH, N. H., COVERED FILTERS. UNDERDRAINS AND GRAVEL BEING PLACED IN POSITION

v = the velocity of the water in a solid column of the same area as that of the sand, in meters, daily, or approximately, in million gallons per acre daily.

c = a constant; its value for clean sands is about 1,000, and for filters that have been some time in service it is about 800.

d = the effective size of the sand grain in millimeters.

h = the loss of head due to passing through the sand at the given rate.

l = the thickness of the sand layer.

t = the temperature of the water in degrees Fahrenheit.

The formula only applies when the pores of the sand are entirely filled with water, when the sand is well compacted, and when there is no clogging of the pores. It is also applicable only in the case of sands from 0.10 to 3.00 mm. in effective size, and with uniformity coefficients lower than 5.

From this formula the loss of head, h, can readily be found if the rate of filtration, the effective size of the sand and the depth of the filtering materials are given.

Depth of Sand.—The effect of the size of the sand grain, uniformity coefficient, depth of the sand layer and the rate of filtration, on the efficiency of the process of slow sand-filtration were fully discussed in Chapter III.

The usual depth of sand in the European filters is from 2 to 3 feet, but in most of them, however, the gravel layers under the sand are very much

thicker than necessary. It is advisable to make the gravel layers as thin as would be safe, in order that the total depth of the filter may not be unduly increased. The proper depth for the sand will vary according to its character and the character of the water. Very coarse sands require thick beds, while very fine sands do not require so great a thickness. The best thickness can only be determined from a study of the sand and the results that must be obtained. Generally, with ordinary sands, such as would be called good mortar sands, and ordinary waters, troubled neither with excessively fine clay turbidity nor algæ growths, a depth of five feet is best. With finer sands four feet may be sufficient.

Character of Sand.—The sand should be free from clay, loam and vegetal matter, and preferably also free from particles of limestone and other mineral matter that might affect the water injuriously. The uniformity coefficient should be as low as possible, and the sand grains hard and firm so as not to disintegrate under the action of the water. Sands containing lime and magnesia will render the water somewhat harder after filtration. Dirty sands should be washed to remove the dirt, before being placed in the filters, as such matter would cause clogging and reduced efficiency. Particular care should be taken to secure sand of uniform character and fineness, because if several different sizes are used in the same bed they will, on account of offering different resistances, cause different rates of filtration in different parts of the bed. Also, if the uniformity coefficient

Plate IX.—Interior View of Ashland, Wis., Covered Filters. Taken when the Filtering Sand was being placed in position.

is high there will necessarily be a good deal of sand lost during washing, as the velocity necessary to wash the larger grains may be great enough to float the finer ones away.

Placing Sand in Filters.—A great deal of care is necessary in placing the sand in the filters to secure uniform density of the entire bed. It should not be deposited in one layer, nor in thin layers, each spread out and levelled, but rather in two or three layers, the face of each layer being stepped back several feet behind the next lower one, and all carried continuously across the bed of the full thickness. After it is in place the top should be levelled off to a flat horizontal surface, planks being placed on the sand for the men to work on, so that their boots will not compact the surface.

A view of the Somersworth, N. H., covered slow sand-filter, taken when the filtering-sand was being placed in position in three layers, is given in Plate X.

Placing the Gravel.—In placing the gravel around the underdrains care must be taken to see that it is thoroughly settled before the sand is placed in the filter, because subsequent settling may produce vertical lamination through the sand, allowing unfiltered water to pass down to the underdrains. The gravel should be deep enough to bury the lateral underdrains, and should cover the space between them. It should not, however, extend clear to the side-walls, or edges, of the filters, but should stop 3 or 4 feet from the walls so as to force the water to flow along the bottom of the filter under the sand, as

was done at Albany by Mr. Allen Hazen. If the concrete side-walls are made smooth when first built, and are then washed down with a brush coat of neat Portland cement, good results will be obtained in preventing the too rapid passage of the water between the sand and wall surface. As stated in chapter III., the walls and piers should be battered below the sand line so that the sand will settle tightly against them; this provision ought to make a tight joint between the sand and walls. It is not good practice to plaster the inside of the walls of filters below the sand line with a coat of cement applied with a trowel, because such coats frequently adhere in spots only, leaving spaces behind through which the water can flow if cracks should develop in the plastering. Brick walls and piers are also to be looked upon with more suspicion than if made of concrete, because, as bricks are generally laid, the mortar cannot be depended upon to adhere closely to the bricks in the vertical joints, and, therefore, unfiltered water may follow cracks and joints to the bottom of the filter. The stopping of the gravel layer a few feet from the sides of the filters is designed to correct this evil. It is also better to finish the inside plastering, where it is necessary, with a felt float rather than with a trowel, as hard polished neat-cement surfaces are almost sure to check after setting.

Sand Washing.—In case the sand is dirty and the uniformity coefficient too high, it should be screened to remove the large pebbles, and then washed to re-

Plate X.—Interior View of Somersworth, N. H., Covered Filters. Showing the Filtering Sand being put in place in three layers, the Underdrains and the Gravel surrounding them.

move the dirt. The sand washers in common use by contractors, consisting of revolving screens and cylinders with sprays of water playing through the sand, are quite effective for removing the clay and dirt. They usually have a helix on the interior of the cylinder, which works the sand up to the high end, discharging it into cars after it is washed. The dirty water and fine particles are washed out at the lower end. This form of washer is in use in Berlin. Another—and for some reasons a better—washer is the form now popularly known as the Hamburg washer, from its use in an improved form at the Hamburg filters. The washer consists of a series of hoppers with ejector nozzles perforating the bottom of each, and pipes and troughs arranged so that the sand from each hopper is lifted to the next, the fine dirt going over the sides of the hoppers with the wash-water. This apparatus is shown in sketch in Figs. 22, 23 and 24, and in the photographic views, Plates XIII and XIV, and is the form now used almost exclusively in modern filter plants, because of the convenience and thoroughness with which the washing of the dirty sand removed after cleaning filter-beds can be done.

Sand may be washed quite clean with a hose if other apparatus is not at hand. A platform should be prepared with walls around all sides, and a movable-board front. The bottom of the platform may be of wood or of brick, and should slope toward the open end. The sand is placed in a pile at the high end of the platform and the water played on it from

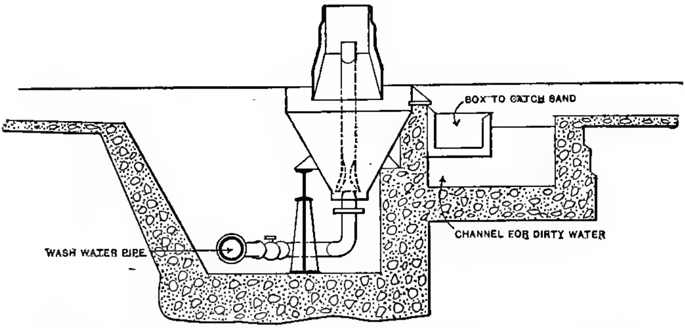

FIG. 22.—CROSS-SECTION THROUGH EJECTOR SAND-WASHER.

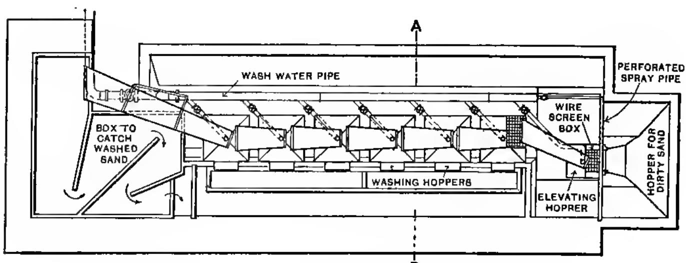

FIG. 23.—PLAN OF EJECTOR SAND-WASHER.

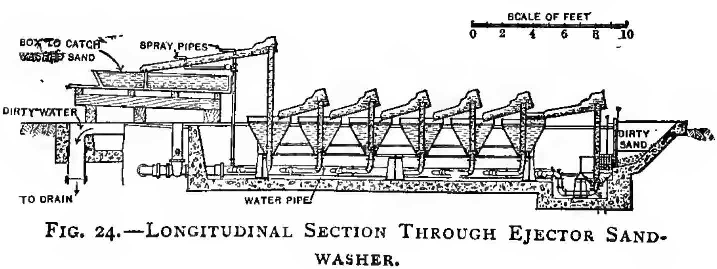

FIG. 24.—LONGITUDINAL SECTION THROUGH EJECTOR SAND-WASHER.

the hose. The water and dirt overflow the weir in front, and the sand remains on the platform. The sand is kept thrown back as the washing progresses. The washing has been carried far enough when the wash-water runs clear. The washing is done in this way at Antwerp and at some of the London filter plants.

At Edinburgh the sand is washed in boxes having perforated false bottoms, the water forced up through the perforations carrying the dirt over the edges of the boxes. Of course, in all plants experiment is necessary to determine the quantity of water necessary to properly wash the sand, and the force with which it must be used, so as not to carry off too great a proportion of the finer particles.

The cost of washing sand, and the quantity of wash-water required, will be discussed under the operation of slow sand-filters.

Regulating Apparatus.—Generally arrangements are made for keeping the surface of the water on the filters at a constant height, allowing the water to fall in the regulating chamber as the frictional resistances increase with service. This is accomplished by placing a valve, operated by a float resting on the surface of the water in the filter, on the inlet for raw water. In some works, however, the water surface in the regulating chamber is kept at a constant level, and the depth of the water on the filters is allowed to increase, as clogging takes place, while in others the water in both the regulating chamber and the filters is allowed to fluctuate, arrangements being made to

prevent too great a depth in the filter by hand-regulation of the inlet valve and by an overflow. Examples of each kind are to be found in the well-known filters of Europe. To the first class belongs the apparatus used at Hamburg, to the second the older Berlin apparatus, and to the third the automatic devices used at Warsaw and Zürich. Many plants have no special apparatus for regulating the height of water on the filters, but are worked by opening or closing a valve on the feed-pipe, by hand, in accordance with the necessities of service. This is the case at Zürich, on the earlier Berlin filters, and is the general English practice. At Hamburg and Leeuwarden, the new filters at Berlin, the Albany filters, and at several other places the depth is automatically limited by a float upon the surface of the water on the filters. This float opens and closes a valve on the inlet pipe. Care should be taken to provide some sort of stilling chamber around the float, so that it may not be thrown out of line and thus jam the valve and cause it to become inoperative.

In passing through the filters a certain amount of head is used up in forcing the water, with the proper velocity, through the sand and underdrains. This loss of head increases with the length of time the filter has been in service. When the filter will not deliver the requisite amount of water, with the maximum loss of head allowed, the filters must be cleaned. In most of the European plants the loss of head is limited to from 24 to 36 inches, but in some cases

these limits are exceeded. There is no reason why the loss of head should not be as great as the depth of water over the filters, or say from 5 to 6 feet in ordinary cases. When the loss of head is greater than the depth of water over the sand, clogging may occur just below the surface of the sand, on account of the accumulation of matter on the surface and the liberation of bubbles of air from the water. If the regulation of the rate of filtration were done by throttling the underdrain before discharging the water into the regulating chamber, negative heads could be used and greater periods of time between scraping would be the result. In other words, the section of greatest resistance should be transferred from the surface of the sand to the outlet of the underdrains, if negative heads are to be used successfully. This occurs with some forms of automatic regulating apparatus and hence, with such, negative heads may be employed, at least up to the limit of economical construction.

Regulating apparatuses are of two kinds: those operated entirely by hand, and those which are automatic in their operation. Hand-regulators were used in England as early as 1839 on the filters built by James Simpson for the Chelsea Water Company at London. The apparatus consisted merely of a valve in the supply-pipe, and one in the discharge-pipe from the underdrains. A similar arrangement was used at the Stralau works at Berlin, and is in use at Edinburgh, Scotland. In the latter place a weir was added for gauging the quantity of flow. The outlet

from the filters at Shanghai is also a simple sluice-valve, but an automatic double-seated balanced valve on the feed-pipe, operated by a float, keeps the water level on the filters at a constant height. It is evident that this construction was intended to make the filtration head correspond to the fluctuating draft rather than to regulate the flow to a constant rate. Similar arrangements are found in most of the early filters and in many still in use.

Another form of regulator much used in the Eng-

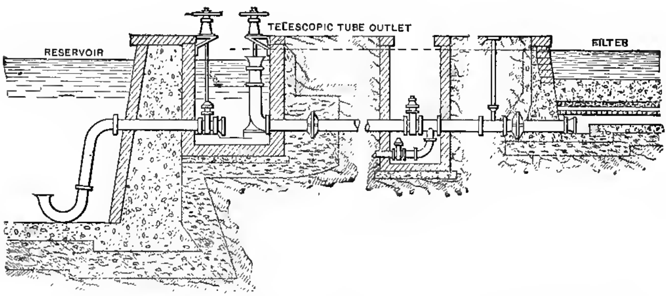

FIG. 25.—REGULATING APPARATUS IN USE AT YOKOHAMA, JAPAN.

lish practice is a telescopic tube, the upper section of which can be raised or lowered by a screw. This form of regulator is in use at the New River Company's filters at London, at the Yokohama water-works in Japan and at Koenigsberg, in Germany (Figs. 25 and 26). In this device a constant discharge, and, therefore, a constant velocity of filtration, is insured by so regulating the height of the top of the telescopic pipe that a constant depth of water flows over its edge. This requires the screwing down of the top of the pipe, as the resistances to filtration become

greater with the clogging of the filter. A modified form of the apparatus, designed by the Stanwix Engineering Company, in 1893, is in use at Ilion, N. Y. It consists of a telescopic tube 13 inches in diameter, inclosed in a tube 20 inches in diameter, the smaller tube being movable and connecting

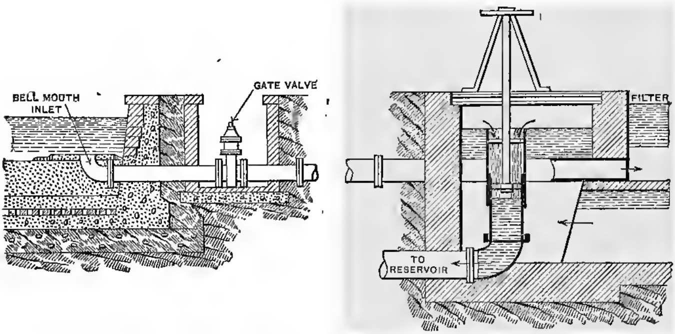

FIG. 26.—REGULATOR IN USE AT KOENIGSBERG, GERMANY.

through a fixed diaphragm in the 20-inch pipe with the pipe leading to the filtered-water reservoir.

At Antwerp the water from the filter underdrains comes out at the tops of telescopic tubes and falls on spreaders to promote aeration after having absorbed iron in the filter-beds. A similar arrangement has also been used quite extensively in Japan by Professor Burton. The usual methods of rating the discharge of the telescopic tube are by measurement of the amount of water that it discharges, with different depths of water over the lip of the pipe, by observing the actual quantity by measurement, or by weir gauging.

In 1884 Mr. Henry C. Gill designed the regulating apparatus for the Lake Tegel filters at Berlin. This apparatus is still in use there and also at the new Lake Mueggle works. It is shown in Fig. 27. There

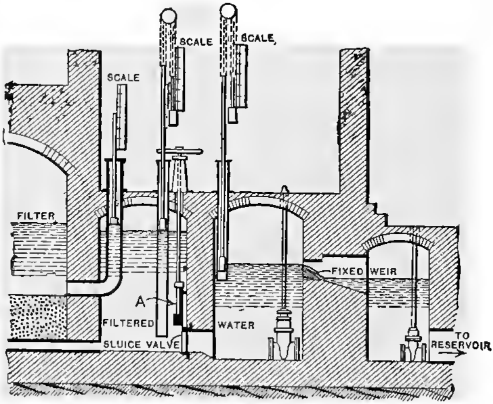

FIG. 27.—REGULATOR DESIGNED BY HENRY C. GILL AND USED AT THE BERLIN FILTER PLANTS.

are three chambers; the water from the underdrains entering freely into the first, then into the second through an opening controlled by a valve at the bottom. In the wall of the second chamber a fixed weir of known dimensions is placed. After flowing over the weir the water falls into the third chamber, which connects with the channel leading to the filtered water reservoir. A constant depth of water over the weir is secured by the operation of the valve in the first chamber, which is opened or closed in accordance with the indications of floats in the different chambers and on the water in the filters. By the positions of these floats the attendant can determine

the filtration head, rate of filtration and actual depth of water on the filters, and will regulate the valves accordingly.

The quantity of water discharged over the weir per second of time may be found by the formula $Q = u\frac{2}{3} bh \sqrt{2gh}$, where Q = cubic feet per second, b = width of weir in feet, h = depth of water in feet over the weir, measured back of the weir where the water is level, g = the acceleration of gravity, = 32.2 feet per second, and u = a coefficient to be experimentally determined, its approximate value being about 0.60, but varying between quite wide values with different widths of weir and depths of water flowing over it.

In 1866 Mr. James P. Kirkwood recommended for St. Louis an apparatus for regulating the rate of filtration, which consisted of a weir that could be raised or lowered until the proper quantity would flow over it. This is shown in Fig. 28. The regulating apparatus at Hamburg (Fig. 29) is a modification of Kirkwood's, with also a submerged orifice leading from the second to the third chambers, through which the discharge can be further measured. In the Hamburg apparatus a scale is attached to the movable weir and a floating index on the surface of the water in the chamber shows always the depth of water running over the weir; the scale also gives the height of the water in the measuring chamber relative to that in the filters, the water in the filters being kept at a constant level by means of a float operating a

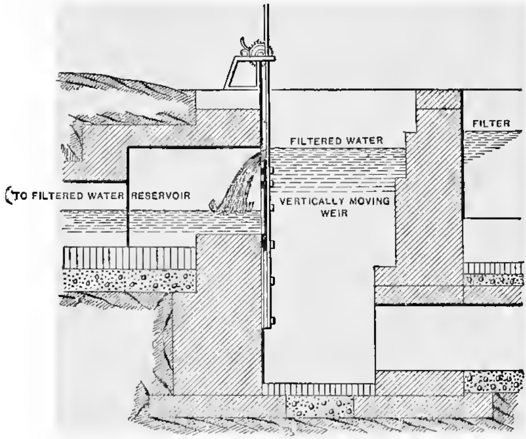

FIG. 28.—REGULATOR RECOMMENDED BY JAS. P. KIRKWOOD FOR ST. LOUIS.

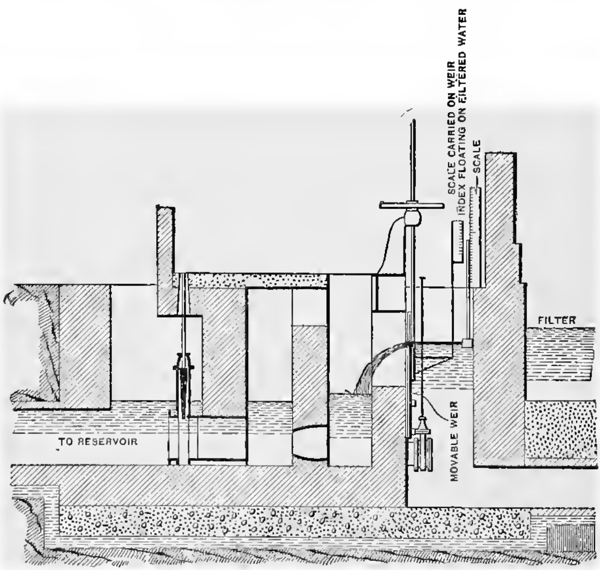

FIG. 29.—REGULATING APPARATUS IN USE AT HAMBURG, GERMANY. F. ANDREAS MEYER, ENGINEER.

balanced valve on the supply main. The discharge over this weir and also over that of the Kirkwood apparatus would be calculated by the formula just given for the Berlin apparatus.

At Albany Mr. Allen Hazen has adopted a method of regulation somewhat different from any in use elsewhere. (Fig. 30.) The water from the underdrains

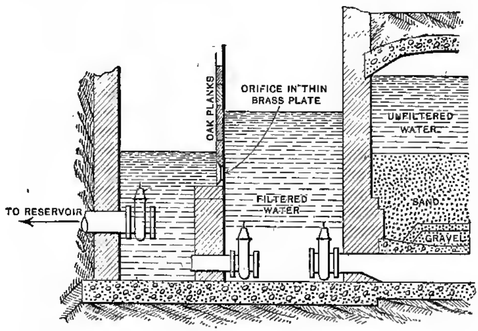

FIG. 30.—REGULATING APPARATUS DESIGNED BY ALLEN HAZEN FOR THE ALBANY FILTERS.

enters a chamber, in one wall of which is placed a thin plate, with a long, narrow orifice of fixed dimensions through its centre. The water flows into the second chamber through this orifice; floats resting on the water in each chamber show the difference of level between the water surface each side of the plate, and from this difference of level the discharge can be computed. Indexes and scales connected with the floats show the filtration head and the rate of filtration. When the water in the second chamber falls below the centre of the orifice, the float in that chamber is prevented, by an ingenious arrangement, from

sinking lower than that point, and the discharge through the orifice is then a free discharge into the air. The size of the opening is so proportioned that a certain maximum rate of filtration may not be exceeded in service. The regulation of the rate of flow is effected by valves worked by hand. So long as a constant difference of level is maintained between the water surfaces either side of the orifice, a constant discharge will ensue. With a little care the rate can be regulated very closely.

Automatic regulators may be classed in two groups: those operated by the action of floats on the surface of the filtered water and those in which, with varying rates of draft, the velocity, or energy of the water, as it is drawn from the filters, is made to effect its own regulation by opening or closing a balanced valve.

Of the automatic regulators operated by floats, those at Zurich (Fig. 31) and Warsaw (Fig. 32) are the most prominent of the European types. In each there is a telescopic joint of pipe, having vertical slits around the periphery at the top, suspended from a float. The float swims on the surface of the filtered water in the regulating chamber, and the filtered water escapes to the reservoir through this telescopic pipe. If the top of the pipe is kept at a constant depth below the surface of the filtered water a constant flow will be established. The depth of immersion of the pipe in the Zurich apparatus is governed by a screw which alters the relative height of the float and pipe. The float carrying the pipe is

free to move vertically, the screw-stem being square above the float and sliding through the hub of the

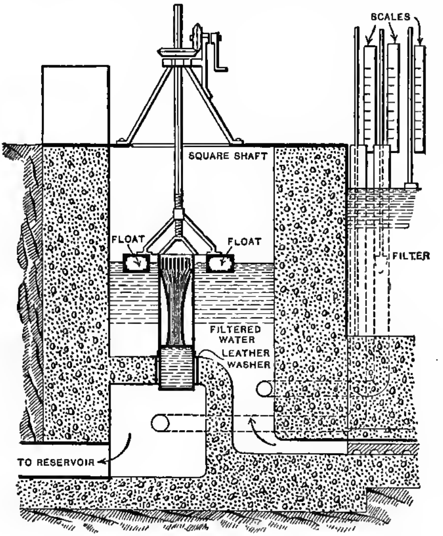

FIG. 31.—REGULATOR IN USE IN ZURICH, SWITZERLAND M. PETER, ENGINEER.

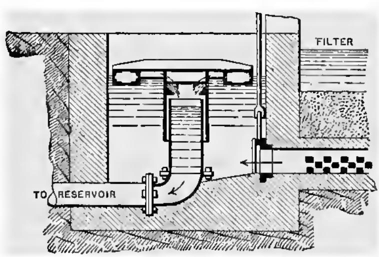

FIG. 32.—REGULATOR DESIGNED BY MR. WM. H. LINDLEY FOR THE FILTERS AT WARSAW, POLAND.

gear wheels above. In the Warsaw apparatus, designed by Mr. William H. Lindley, the relative po-

sitions of float and pipe are fixed and the rate of discharge is regulated by a collar, the moving of which opens or closes an orifice at the top. To Mr. Lindley is due the credit of first advocating the separate and automatic regulation of slow sand-filters.

A modification of Mr. Lindley's regulator (Fig. 33) was proposed for the regulation of the filters for

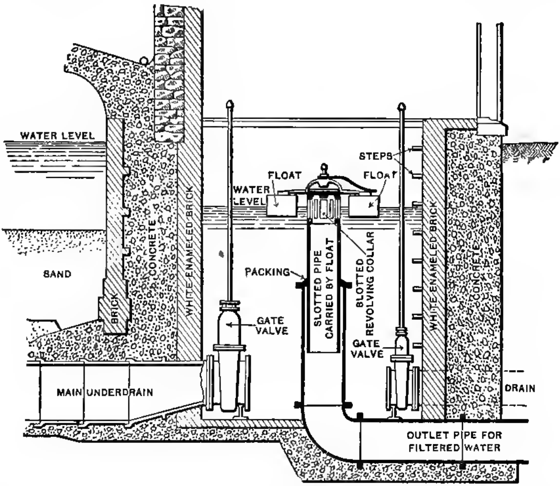

FIG. 33.—TYPE OF REGULATOR SUGGESTED BY THE MAYOR'S EXPERT WATER COMMISSION FOR PHILADELPHIA, PA.

Philadelphia. The difficulty with these automatic devices is that sometimes the floats are not given sufficient margin of buoyancy to overcome instantly the friction of the packing around the telescopic pipe, as the water level changes in the regulating chamber, and this may affect the depth of immersion of the tube and consequently the rate of discharge. For

this reason deep, narrow slots around the periphery of the tube are better than wide shallow ones, the discharge through the former being affected in a lesser degree for a given change of depth of immersion than through the latter. With proper details of design and construction this trouble can be rectified.

The regulator shown in Fig. 34 was designed by

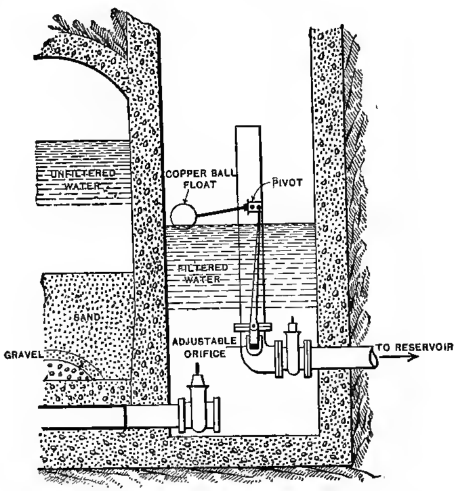

FIG. 34.—REGULATING APPARATUS DESIGNED BY THE AUTHOR FOR THE TOME INSTITUTE FILTERS.

the author for the Tome Institute filters. The water from the filters discharges into a well through which the pipe leading to the filtered-water reservoir rises to above the level of the water on the filters. A rectangular orifice is cut through one side of the pipe on line with its central horizontal axis. The orifice is

formed in a thin plate with beveled edges, and one side is movable vertically, like a slide. This slide is attached to a rod connecting with the end of a lever operated by a ball-float and pivoted to the pipe. As the water-level in the well rises the slide will close the orifice proportionately. The size of the orifice is such that if the water-level in the filtered-water reservoir were below the orifice, the rate of discharge would be constant whether the water in the well stood 6.5 feet or .5 foot above the orifice, and this rate would be 50 per cent. greater than the rate at which the filters are to operate normally. When the draft on the filters is normal the orifice is submerged. If the draft is below normal the filters are automatically and slowly shut off.

In all the foregoing forms of automatic regulator the discharge from the beds is free, and the difference in level between the water on the filters and in the chambers adjusts itself automatically to the increasing resistances.

The apparatus used at Worms (Fig. 35), operated by a float on the surface of the unfiltered water, requires constant adjustment as the resistances increase, and does not, it would seem, offer the advantages given by the more simple forms used at Warsaw and Zurich.

The automatic regulator, designed by Professor W. K. Burton, and shown in Fig. 36, utilizes the velocity of the water, as it is discharged from the filter, to effect its own regulation. It is in use in the filters at Tokio and Osaka, Japan, and consists of a bal-

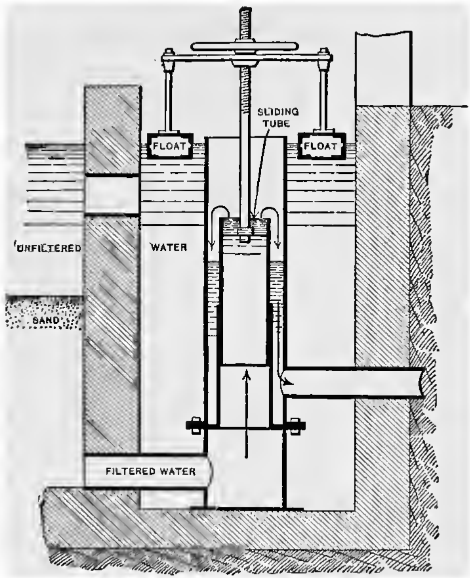

FIG. 35.—REGULATOR IN USE AT WORMS, GERMANY.

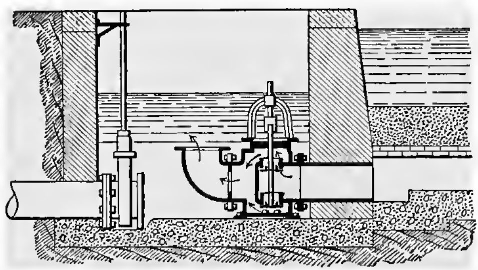

FIG. 36.—REGULATOR DESIGNED BY PROF. W. K. BURTON AND IN USE AT TOKIO AND OSAKA, JAPAN.

anced valve opened or closed by differences in pressure on the opposite sides of a piston attached to the valve-stem. This difference of pressure is induced by placing a diaphragm, with an orifice in its centre, in the outlet of the underdrain pipe. In passing through this orifice the flow of the water is retarded; this produces pressure on the lower side of the piston, as a consequence of which the valve is closed automatically.

There is still room for the exercise of inventive genius in the improvement of the regulating apparatus for slow sand-filters. Some reliable arrangement which, while preventing a certain maximum rate being exceeded, would automatically permit the use of any rate below the maximum, at the same time giving a continuous record of the actual rate, would be very useful. Such an apparatus would allow the filters to adjust themselves to some extent to the rate of draft. As has already been explained, this practice has been found to be safe, between certain limits, and gives to the plant a flexibility in operation that at times may be very desirable.

Cost of Slow Sand-filters.—The cost of construcing slow sand-filter plants depends entirely upon local conditions. It is convenient to refer the cost to a unit of area rather than to a unit of quantity of water filtered, because some waters may be filtered more rapidly than others, and hence the cost per million gallons filtered would not be a satisfactory unit for comparison. The cost per acre of filter surface, however, is a very convenient and expressive unit, as

from it an idea may be mentally and rapidly formed of the cost of a proposed plant. Small filter-beds naturally cost more per acre than large ones, because, while the cost of floors, roofs and piers will be about the same per acre of area, the volume of masonry in the side-walls of small filters will be much greater in proportion to the area than in the large ones.

Among the features that influence the cost of filter plants are the rate at which they are to be operated, the arrangement of the beds, the topography and geological structure of the region, the local prices of materials and labor, the legal length of a day, the expenses of administration, the season of the year in which the work is undertaken, the rate at which the work will have to be pushed and the difficulties in the transportation of materials and the securing of labor.

It is generally found that the filters should be so placed that the water level, when the filters are filled, will be about at the level of the natural surface of the ground. It also seems to make little difference in the cost of excavation whether the filters are built on level ground or on sloping ground, with the beds stepped down in terraces, even when there is considerable difference in elevation between different parts of the area. For instance, in the data given in Table XII, the differences in elevation of the natural surface of the ground in different parts of plants Nos. 1 and 2 was fifteen feet; in plants Nos. 3 and 4, ten feet; in plant No. 5, thirty feet, and in plants Nos. 6 and 7, five feet. In plant No. 8 the excavation was

nearly all slate rock. In plants Nos. 9 and 10 there was also a large amount of rock excavation.

Data, concerning the cost of filter plants, derived from works in operation, must be interpreted with a thorough understanding of what these costs include, and a knowledge of the local conditions. Some works, very simple in design, requiring no pumping machinery, no difficult foundations and no excessive haul on materials, can be built cheaply, while others, where the conditions are not so favorable, may cost much more. In the estimates of cost of the filter plants for the improvement of the Philadelphia water-supply, the transporting of the materials to the filter sites was an item of considerable magnitude. Its effect, exclusive of the hauling of the piping, was to increase the cost of the remote plants at the rate of about $4,500 per acre above the cost of the plants more favorably located; the beds were covered and had an area of ¾ acre each. It is necessary therefore when the plant is to be built at a point where considerable difficulties attend the delivery of materials, to add to their cost the expense of transporting them to the site of the works.

In Table XII are classified the unit costs per acre of some of the component parts of several large filter plants in the United States for which estimates of cost have recently been made. All the filters were to have been covered and to have an area of about ¾ acre each. The estimates do not include the cost of the piping to and from the filters, the cost of pumping plants, of sedimentation basins or filtered-

water reservoirs, but do include the making of roads, sodding of embankments, seeding of lawns, and all work connected with the filters, including the underdrains, filtering materials, regulating apparatus, etc.

TABLE XII.

Plant.	Number of Beds.	Excavation, including Sodding, Seeding, etc.	Sand-washers, including Piping for Wash-water.	Covered Filters Complete, including Filtering Materials, etc.	Electric-lighting Plant.	Tramways for Sand-Hauling, including Cars.	Residences, Shelters, Offices, Fences, Storerooms, etc.
1	13	$3,200	$328	$50,313	$640	$ 536	$3600
2	26	3,200	276	44,348	772	572	2308
3	8	3,208	368	50,616	....	468	5136
4	18	2,852	336	50,412	....	444	2068
5	27	3,276	276	49,808	740	588	1904
6	24	3,076	312	50,228	....	540	2136
7	138	3,040	336	49,808	....	528	1448
8	136	24,716	412	50,000	1570	6[illegible]6	1508
9	133	8,000	280	50,000	1200	452	1416
10	70	16,048	290	46,668	1240	536	1500

The Albany covered filters cost about $38,000 per acre, including the filtering materials, but excluding the excavation, sand-washing machinery, buildings, pumps, settling basins, and piping to and from the filters, and about $45,600 per acre, including all the above items, except the pumps and sedimentation reservoirs. Small plants cost very much more in proportion than large ones. For instance, for a plant consisting of three open filters, with a total area of 0.19 acre, the actual costs per acre were as follows:

Excavation, grading, etc.	$8,200
Sand-washing machinery	8,400
Filter-beds, including sand, etc.	100,000
Tramways and equipment	816

For another plant consisting of two very small covered filters with a total area of 0.013 acre, the costs per acre were as follows:

Excavation, grading, etc.	$17,000
Covered filters, including sand, etc. . . .	115,400

The cost of the Nyack filters with a total area of 0.38 acre was, for excavation, including foundations, sheet piling, etc., $30,500 per acre, and for the open filters complete $46,700 per acre. The covered slow sand-filters at Ashland, Wis., with an area of half an acre, cost at the rate of a little under $70,000 per acre.

Statements of cost per acre must therefore be interpreted understandingly. The necessary piping, the drains, auxiliary pumping machinery for lifting the water to the filters from the settling basins, or into the settling basins from the source of supply, the land, buildings and other necessary adjuncts may amount to nearly as much as the cost of the filters. These conditions are so varying that statements of their cost in individual cases would be of little value here. The cost of the bacteriological and chemical laboratories cannot well be stated in a price per acre, because one laboratory generally serves an entire municipal plant, and requires about the same equipment for a small plant as for a large one. The cost of such a laboratory, properly equipped, is about $30,000, but may be more or less than this by a considerable amount, according to circumstances.

The cost of roofing the Albany filters, including

the piers, was about $0.315 per square foot, or a little under $14,000 per acre. In the estimates given in the preceding tabulation the cost of the roofing was, in most cases, very close to this figure.

OPERATION.

For convenience in operating the plant it will be advantageous to place the filtered-water reservoir at such a height that the filtered water may be conducted to it by gravity. The highest water level in the reservoir should be such that it will not cause back water on the filters and thus limit the filtration head in the different beds when the plant is operating at its maximum capacity. Such an arrangement will permit the filters to operate independently when the draft is normal, while at the same time it will cause the water level in the reservoir and regulating chambers to rise when the draft falls below normal, slowly and automatically reducing the filtration head on the filters and affecting those first which have been longest in service. Upon the draft again being increased the water level in the reservoir will fall and the rate of filtration in the different beds will gradually be increased to the rates at which they were last operating. This principle is applicable to both the automatic regulators and the submerged-orifice apparatus designed for the Albany filters by Mr. Allen Hazen. The effect of the gradual changing of the rate of filtration between reasonable limits has already been shown to have no bad effects on the qual-

ity of the effluent, while the adoption of such a plan offers many advantages.

Scraping Slow Sand-filter Beds.—After a filter-bed has been in operation for a considerable time it becomes so clogged at the surface that the water cannot pass through it at the prescribed rate. When this time comes it is necessary to put out of service and clean the bed. The first operation will be to drain off the raw water standing above the sand, and lower its level below the surface of the filter so that the workmen may enter after the sand is hard enough to bear their weight. Cleaning is now done by hand, although undoubtedly improvements in methods will be brought out as filter plants multiply. The workmen are furnished with broad flat shovels or scrapers with which they skim off the dirty top layer of the sand to sufficient depth to remove the clogging—from $\frac{3}{8}$ inch to a little over an inch, generally, averaging perhaps somewhat less than $\frac{3}{4}$ inch. The method is illustrated in Plate XI. This material is heaped up in piles on the surface of the filter and then removed in wheelbarrows on plank runways, or in cars running on movable tracks. In some cases the dirty sand is lifted out of the manholes of covered filters by derricks. Wheelbarrows are generally used in small plants, and in large ones wheelbarrows to get the sand to the tramway, and cars from there to the sand-washers. The sand, as it is removed, is taken to the court and deposited in piles near the sand-washers. The washing is done only in warm weather, the winter's accumulations being allowed to stand

PLATE XI.—METHOD OF SCRAPING SLOW SAND FILTERS.

over till spring. Storage-room for this material must therefore be provided, as washing can not be properly done in freezing weather.

The cost of the labor of scraping filters varies considerably in different plants and in different countries.

Mr. George I. Bailey gives the following data* for the Albany plant:

Average depth of sand removed at each scraping.......... $\frac{5}{8}$ in.
Hours of labor to scrape 1 acre..............................67
Wheeling out scraped sand; average haul going and coming, 600 feet; speed per man per hour....................1.18 miles
Quantity of sand wheeled out per hour's work.......0.38 cu. yd.
Quantity of sand washed per hour's work............0.41 cu. yd.
Quantity of water used for washing sand..........12–14 volumes
Quantity of sand replaced per hour's work...........0.52 cu. yd.
Quantity of water filtered between scrapings, 66,600,000 gallons per acre of filter surface.

The refilling was done mostly by extra labor.

Cost of Scraping.—The time required for scraping an acre of filter surface ranges from 65 hours to about 300 hours in the different plants from which the author has been able to obtain data; a fair and ordinarily attainable result with covered filters would be about 175 hours per acre. The annual deep scraping requires much more time than this and may be estimated by the cubic yard when the quantity to be removed is known. Ordinarily, at such times, the sand will have to be taken out for a depth of from 4 to 8 inches, but in some cases it may be necessary to remove it all down to the surface of the

* Trans. Am. Soc. C. E., vol. XLIII. p. 296.

gravel. At Lawrence, Mass., in 1898, the filters became partially clogged, so that their capacity was considerably reduced. An investigation by the State Board of Health revealed in the gravel a growth of crenothrix, which had caused a deposit of iron-rust to such an extent around and between the stones that the water could not pass freely into the underdrains. The growth of crenothrix was found to be due to the pumping of the water away from the filters too rapidly, thus unduly lowering its level and permitting air to enter the underdrains. The trouble was rectified by excavating a large part of the area and renewing the underdrainage system.

After the annual deep scraping it is customary to loosen up the remaining sand for a depth of several inches and allow the filter to stand for some time, several days in some instances, before refilling with washed sand. The surface, after scraping, is raked over to make it level and smooth and to remove the prints of the workmen's boots. In some places, particularly in England, it is customary, once a year, to trench the sand down to the gravel, filling the trenches with washed sand, and afterward covering this with the sand taken from the trenches. Experiments have also been made with the "seeding" of the beds after scraping by spreading a thin layer of partially clogged sand over the filters to start the biological action more quickly, but so far as I have been able to learn the process has not proven of any advantage.

The quantity of sand removed at a scraping, assuming the layer taken off to be $\frac{3}{8}$ inch deep, would

be about $50\frac{1}{2}$ cubic yards per acre. If it were necessary to scrape 13 times during the year, including the annual deep scraping, and if the latter were 4 inches deep, the quantity of sand removed, per acre, would be about 1,150 cubic yards, equivalent to an average depth of $8\frac{1}{2}$ inches. At Lawrence the quantity has been slightly less than this.

Frequency of Scraping.—The frequency with which scraping will be required depends principally on the character of the water, being necessary more frequently at some seasons of the year than at others. The following table, compiled from the reports of the Lawrence Water Board for 1897 and 1898, show the number of times each of the filter-beds was scraped during these two years.

TABLE XIII.

Year.	Month.	Number of Filter-bed.																								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1897	Jan.	1	1	1	1	1	1	1				1	1	1	1	1	1	1	1	1	1					
	Feb.	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	1	1	1	1	1
	March	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	2	2	2	2	2	2	2
	Apr.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	May	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	June	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	July	2	2	2	2	3	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1
	Aug.	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	1	1	2	1	1	1
	Sept.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
	Oct.	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Nov.	2	2	2	3	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Dec.	1	1	1	1	1	2	2	1	1	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1
1898	Jan.									1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Feb.	2	2	2	2	2	2	2	2	2	1	1	1	1												
	March	1	1	1	1	1	1	1	1	1	2	2	2	2	2	1	1	1	1	1	2	2	2	1	1	2
	April	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	May	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	June	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	July	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Aug.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
	Sept.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2
	Oct.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1				1
	Nov.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Dec.	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1				1	1			

The average number of scrapings at Lawrence has been about 14 per year.

In Zurich, notwithstanding the clearness of the lake water, the filters require scraping quite frequently at times, on account of the presence of certain organisms in the water in the summer season which clog the surface of the sand very rapidly. The following tabulation exhibits the data regarding the scraping of the Zurich filters for several years.

TABLE XIV.

Year.............. ... Days between Scrapings.	1894. 7 Filters.	1895. 7 Filters.	1896. 10 Filters.	1897. 10 Filters.
Minimum....................	9	5	5	6
Maximum....................	47	28	42	64
Average.....................	21	$13\frac{1}{2}$	17	17
Average number of scrapings per year of each bed.	....	23	18	21

At the Lake Tegel works in Berlin the minimum period of time between scrapings, that is, when algæ growths are most flourishing, is about 10 days; the maximum period is about 80 days, occurring in the winter time, and the average period 30 days. At Altona the minimum period is 10 and the maximum 50 days.

Where scraping would be required oftener, on the average, than twice a month, it may generally be assumed that some preliminary treatment before filtration would be advisable. This may be sedimentation, with or without coagulation, or some other

measure for the removal of the suspended matter or growths of algæ in the water.

In existing plants the quantity of water filtered between scrapings, where the water has had proper treatment before being admitted to the filters, ranges from about 40 to 100 million gallons per acre. At Stralau, Berlin, in 1893, the quantity delivered by the open filters between scrapings during the period when algæ growths were most flourishing was on one occasion reduced to only 14 million gallons per acre.

Effect of Covers on Frequency of Scraping.—In Zurich it was found that the open filters required scraping more often than those which were covered. In 1887 the average period between cleanings of the covered filters was 77 days, while the uncovered filters required cleaning on the average every 48 days. In 1892 and 1893 both kinds of filters were cleaned more frequently than in 1887, yet the open filters required the treatment at shorter intervals than the covered ones, as is shown by the following tables taken from the Stadtrat Report of 1893:

TABLE XV.

NUMBER OF DAYS BETWEEN CLEANINGS.

	Covered Filters.		Open Filters.	
	1892.	1893.	1892.	1893.*
Minimum	19	12	11	13
Maximum	69	73	50	39
Average	36	27	23	20

* 1893 to the middle of September.

TABLE XVI.

GALLONS OF WATER FILTERED BETWEEN CLEANINGS.

	Covered Filters.		Open Filters.	
	1892.	1893.	1892.	1893.
Minimum...	26,420,000	9,168,000	19,419,000	13,606,000
Maximum..	76,618,000	116,658,000	47,952,000	51,572,000
Average..	44,914,000	31,255,000	29,855,000	21,532,000

A thick layer of green algæ would frequently grow upon each of the uncovered filters. This growth not only rapidly clogged the filters, but also gave much trouble in other directions. The rising of bubbles of gas through the water, tearing loose and carrying with them patches of the algæ growths, would disturb the surface of the filters and allow raw water to pass through the bald patches too rapidly. The covered filters were not troubled in this way, because the algæ could not grow in the dark.

In regard to the growth of algæ on filter surfaces, Mr. Charles E. Fowler, Superintendent and Engineer of Public Works, Poughkeepsie, N. Y., says: * "The algæ growths on the sand in summer are quite as troublesome and almost as expensive as ice and frost in winter. Like ice, they can develop on an unlimited area in the same time as on a small unit, and will stop a filter and put it out of service just when it should otherwise be doing its best work."

The studies of Dr. Otto Strohmeyer of the growths of microscopic organisms in the sand of the Hamburg filters, and of Dr. Ad. Kemna, of Antwerp,

* Trans. Am. Soc. C. E., vol. XLIII. p. 311.

along similar lines, have brought out, among other things, the very interesting facts that when the vegetation over the sand surface is in a living condition it is a decided aid to the efficiency of the process of filtration, if it does not result in a disturbance of the sand surface, and that some of the algæ exercise a sterilizing influence on the water in which they are growing; also that the flora change with the seasons, and that the decomposition of certain of the organisms, with seasonal changes, notably Anaboena, causes a bad taste in the water. Mr. George C. Whipple, Director of the Mount Prospect Laboratory of the Brooklyn Water-works, has also noticed that when the growth of some of these organisms, particularly Asterionella and Synedra, was luxuriant in the Brooklyn reservoirs the number of water bacteria was unusually low. It may thus be that some of these growths exercise a sterilizing influence on the water, and, therefore, assist in its purification, but it is always at increased cost of operation of the filters on account of the more rapid surface clogging.

At Antwerp the algæ growths are watched carefully, and the filters are operated slowly during the season when such growths are most vigorous, because the evolution of gases breaks loose large masses of the organisms, which, floating to the surface, carry with them parts of the surface film, and leave bare portions of the unclogged sand, through which the water may pass, imperfectly filtered. These facts should in each case be considered in deciding whether or not covers for filters are advisable.

Transportation of Sand to Washers.—The cost of transporting the sand from the filters to the sand-washers and back will depend upon the distance the materials have to be moved and upon the means employed for their transportation. Where wheel-barrows are used the cost may range from 20 cents to 40 cents per cubic yard, each way; if cars are used the cost may be considerably less than this, and a still further reduction may be possible if water-carriage is feasible.

In Plate XII is given a view of the Albany, N. Y., filters, showing the wheeling-gang removing the scraped sand from the filters to the sand-court. This is done by "stint work," for which time and one half is paid. The best record of the gang is as follows:

7.5	barrows per cubic yard.
10.5	barrow-loads per hour's work.
0.087	miles per barrow-load.

The sand-washers, as originally built, are shown in Plate XIII. The dirty sand was wheeled to the washers from the heap in barrows. In Plate XIV is shown an improvement, recently introduced, by which the transportation is done in flowing water instead of wheelbarrows. A portable ejector hopper has been added to the washers, so that the dirty sand may be conveyed from the heap to the washers without the use of wheelbarrows.

Cost of Sand Washing.—After the sand is taken to the ejector washers one man can feed it in as fast as two can take it away after it is washed; the extra

PLATE XII.—ALBANY, N. Y., FILTRATION PLANT. WHEELING OUT SAND REMOVED FROM FILTERS AFTER SCRAPING.

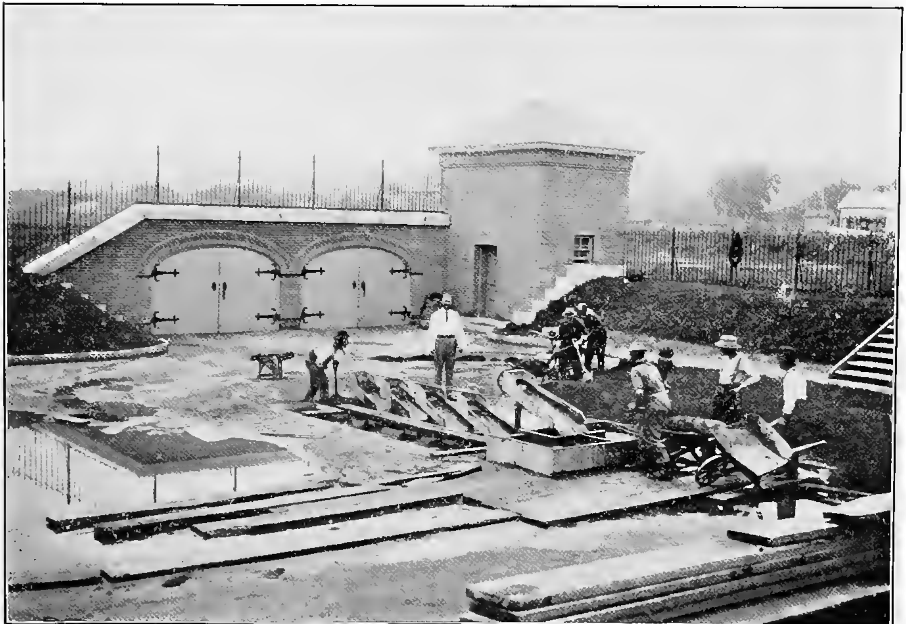

Plate XIII.—Albany Filtration Plant; Sand Washers as originally built. The dirty Sand was wheeled in Wheelbarrows to the Washers.

Plate XIV.—Albany Filtration Plant. Improvement in Sandwashing Machinery. The Sand is conveyed to the Washer through a Pipe by a movable Ejector Hopper and a Stream of Water.

labor amounts to about the time of another man, or, say four men to wash from 16 to 30 cubic yards of sand per day, or from 0.40 to 0.75 cubic yard per hour's work. Washing the sand with water under pressure, in ejector hoppers, takes from 12 to 15 volumes of water to one of sand washed, or, say 325 to 400 cubic feet of water to the cubic yard of sand. This amounts to about one half of 1 per cent. of the water filtered, counting the scrapings about three quarters of an inch deep and the quantity filtered between scrapings about 80,000,000 gallons per acre. An allowance of 1 per cent. of the water filtered for washing sand and wasting will generally be ample.

The Trommel washer, or revolving drum, used at Berlin, is 11 feet long, about 4 feet in diameter, and when turning at the rate of 7 revolutions per minute will wash 4 cubic yards per hour; 4 to 5 men are required for operating it, and about 350 to 390 cubic feet of water are required for properly washing a cubic yard of sand. The cost of washing the sand is given as 31¼ cents per cubic yard, including the delivery to and removal from the washer.

The washing of the sand is generally done with filtered water from the mains, but this is not absolutely necessary, as ordinarily the raw water, unless exceedingly polluted, will give satisfactory results.

If the sand is very fine, or can be had very cheaply, it may not, under some circumstances, pay to wash the sand removed during the periodical scrapings. In such cases new sand is used in refilling.

Lost Sand.—In washing the sand a certain amount, depending upon the uniformity coefficient, is lost by being carried away in the wash-water. Reliable data bearing on this subject are difficult to obtain, but such statements as have come under the author's observation lead to the belief that from about 3 to 10 per cent. of the sand washed is lost in this way. These figures may be high for plants using coarse, uniform sands, but they are certainly not high for those using very fine sands. The amount lost may be controlled, to a certain extent, by carefully regulating the quantity of sand fed to the hoppers, the quantity of water used in washing it, and the pressure of the water. The effect of repeated washings is to slightly increase the effective size of the sand and reduce its uniformity coefficient.

Ice on Open Filters.—Where ice has formed over the water on open filters the general custom is to remove it before scraping, but at Hamburg the cleaning is done with a Mager scraper, a bag having a sharp lip across the edge of the open end. This bag is suspended from a float and is dragged back and forth across the filter, by means of ropes, allowing the water and ice to remain on the filters. The process is reported to be satisfactory. The removal of the ice from such large beds as those at Hamburg would be attended with much inconvenience, not only in the handling of the ice, but in finding a place to store it on the banks.

The scraping of open filters in freezing weather is generally very unsatisfactory from all points of view.

The freezing of the surface of the sand makes it impossible to remove a layer of the same thickness over the whole area, and also may cause a very considerable reduction in the efficiency of filtration by the frost extending down into the bed several inches and forming cracks through which the water may start to filter so rapidly as to wash the clogging matter out and leave spots of less age biologically than the main body of the filter. The difficulty from freezing, however, does not follow until the temperature is several degrees below the freezing point.

Covers for filters may also conduce to economy in operation in point of the amount of sand removed in cleaning during the summer time as well as during the winter. In the open type, on account of the baking of the surface of the filter in the summer under the action of the hot sun, it is often impossible to remove as thin a layer of sand in scraping as could be easily taken off if the baking were prevented.

Refilling after Scraping.—After the filters have been scraped they are refilled with filtered water through the underdrains, the water passing upward through the filtering material until it stands a few inches above the sand. The filter is then allowed to stand for a longer or shorter time before again being placed in operation. This method is much more satisfactory than the older one of filling from above with raw water. In the latter method sub-surface clogging and channels, through which the water may pass freely to the underdrains, are apt to be produced by the entrainment of air bubbles and their rising

through the filters. It is also almost impossible to pass the water over the surface of a filter without washing furrows in the sand. This necessitates the wasting of a considerable amount of the water first passing through.

Double Filtration.—For the purpose of removing turbidity and to prevent the clogging of the filters by algæ growths, double filtration has been practised at Altona, Bremen, Schiedam and Zurich. At Altona it was not found to be of much advantage, but at Bremen it has proven satisfactory. As generally carried out, the method of operation is to pass the filtrate from a new filter, or one which has recently been scraped, through another filter that has been in service for some time. With some waters this process will not prove advantageous, because of the removal from the water, by the first filter, of the constituents necessary for the production of the surface film.

CHAPTER V.

THE PURIFICATION OF WATER BY RAPID SAND-FILTRATION.

THEORY OF RAPID SAND-FILTRATION.

The Coagulant and its Effect on the Efficiency of Filtration.—The discussion which has preceded has had reference only to what takes place naturally in beds of sand when water is passed through them at comparatively slow rates. An attempt to pass water very rapidly through such beds would, in a short time, result in filling up the pores of the bed and producing an effluent no better, and possibly even worse, than the raw water. If, however, a coagulant be introduced into the water, before it is passed through the filters, a considerable degree of purification can be accomplished. Sulphate of alumina has, so far, been found to be the most suitable coagulant for the purpose. This compound, when mixed with water containing a small amount of lime or magnesia, breaks up, forming sulphuric acid and aluminum hydrate. The sulphuric acid unites with the alkaline constituents of the water, while the hydrate of alumina acts as a coagulant, gathering together in flocculent masses the particles of suspended matter in the water. The

hydrate of alumina is a sticky, gelatinous substance, which adheres to the grains of sand as the water passes through the filter, and catches and holds in its mass the bacteria, as well as the particles of clay and other suspended matter in the applied water. Upon this coagulating material depends the efficiency of the well-known mechanical or rapid sand-filters.

As before stated, the aluminum hydrate forms a film of gelatinous or jelly-like material over the top of the sand, as well as around each grain, through which the water must pass and come into intimate contact in passing down through the filter. The suspended matter, including the bacteria, will be retained in the body of the filter. After a certain period of service the filter will become clogged. The cleaning is done by agitating the bed of sand, and at the same time forcing pure water upward through it. The wash-water, containing the impurities that have been retained in the bed, is wasted, or turned into settling basins.

For a number of years experimenters have been trying to produce a cheap, effective coagulating material. Efforts have also been made to cheapen the present processes for the manufacture of sulphate of alumina, but there seems to be no immediate prospect of greatly decreasing its cost by radical changes in methods of manufacture; increased demand, however, would undoubtedly lessen the price in the course of time.

For the removal of turbidity only, the hydrate of iron is an excellent coagulant, but as it is more ex-

pensive than alum, and less efficacious in removing color, it is not used extensively in connection with rapid sand-filters in the United States.

The only objection that has been seriously urged against the use of alum has come from physicians who have believed that the passage of the alum into the distribution pipes in the city, at times when the alkalinity of the water was too low to decompose the entire charge of chemicals being used, might act injuriously on the public health. The only answers to this charge are: that there should be no such accidental overdose in a properly managed plant, and that there are now hundreds of these filters in use for small municipal supplies where the charge of the chemicals is not carefully watched, and yet there is not recorded a single instance where it is proven that the health-tone of the community has been lowered by the use of water filtered with the aid of alum.

Quantity of Coagulant Required.—The efficiency of the process of rapid sand-filtration depends upon the quantity of coagulant used, the time of its application to the water, the composition of the water, the amount of subsidence allowed, the thickness of the sand layer in the filter, the size of the sand grains, the rate at which the filter is operated, the loss of head allowed at the filters, the manner of washing the filters and of operating them, and the care and oversight exercised at all times over all stages of the process.

The effect of using too small a quantity of coagulant will be a low efficiency in the removal of bac-

teria, turbidity and color. The quantity of coagulant used should always be less than corresponds to the alkalinity of the water; in other words, if there is not enough carbonate of lime or magnesia in the water to neutralize the sulphuric acid set free by the chemical reactions, the acidulated water will attack the iron and lead pipes, in the distribution system, and may cause a great deal of trouble. If there is not enough lime in the water, at most seasons of the year, to permit sufficient coagulant to be used, this process will generally not be suited for its purification, as the expense of continuously adding lime or soda-ash, together with the cost of the sulphate of alumina treatment, would probably be higher than the cost of other processes of purification.

Where the water is ordinarily of proper composition, but may be deficient in alkalinity during heavy floods, lime or soda may then, in some cases, be supplied before adding the alum solution. The waters of rivers and streams generally contain much more dissolved alkaline constituents per unit of volume in dry weather than during floods and periods of full flow. The quantity of coagulant must, therefore, generally be more carefully watched during high-water periods than during dry-weather flow. As has been already explained, small upland rivers generally contain more suspended matter, per unit of volume of flow, during floods than during dry weather, but in the case of large lowland rivers the turbidity is often more difficult to remove during dry-weather flow than during floods; each case must, therefore, be

studied by itself, and the treatment must vary in accordance with the conditions and requirements.

The neutralization of the acid, set free by the decomposition of the sulphate of alumina, changes the dissolved carbonates of lime and magnesia to the sulphates of the same bases; in other words, the hardness is changed from temporary to permanent; generally with the small quantities of chemicals required for the treatment of water by this process, the change of a portion of the hardness from temporary to permanent will not be a serious matter.

Mr. Allen Hazen, in reporting on the filtration of the Pittsburgh Water-supply,* places the limit of the amount of alum that may safely be used, at ordinary periods of flow, at three fourths the amount corresponding to the lime in the water, allowing this quantity to be increased about 25 per cent. during periods of high turbidity. This increase is permissible, owing to the ability of such waters to receive a certain amount of chemical without producing coagulation, as noted also by Mr. Fuller in his Louisville report.

The quantity of alum required will depend, therefore, upon the condition of the water and the results desired. In the Providence experiments, Mr. Weston found one half grain per gallon of water sufficient after the filter had reached the stage of effective operation; his method of quickly bringing the filter to condition was to charge it heavily, before starting, with a dose of alum solution, equivalent to 911 grains

* Report of Filtration Commission, Pittsburgh, 1899.

of sulphate of alumina in one pint of water, and then start the filter slowly, bringing it into effective operation in about half an hour, instead of from one to three hours, as required without such dosing. This additional dose raised the average charge to about 0.6 grain per gallon.

In the Pittsburgh, Cincinnati and Louisville experiments the quantity of coagulant varied principally with the degree of turbidity of the water. In Cincinnati and Louisville the problem of purification resolved itself into securing an effluent without turbidity; when this was accomplished the bacterial efficiency, and removal of color and other objectionable qualities, was satisfactory. So far as is known, turbidity has no direct effect on the bacterial efficiency of rapid sand-filters; that such efficiency is greatest when turbidity is highest is accounted for by the fact that the particles of clay causing turbidity are themselves very much smaller than the bacteria, and a medium that will retain the clay particles will not allow the bacteria to pass through. The relation between turbidity and quantity of chemical required at Cincinnati, as given by Mr. Fuller, is shown in Table XVII.

TABLE XVII.

Turbidity, Parts per Million.	Quantity of Sulphate of Aluminum, Grains per Gallon.	Turbidity, Parts per Million.	Quantity of Sulphate of Aluminum, Grains per Gallon.
10	.75	150	2.65
25	1.25	175	2.85
50	1.50	200	3.00
75	1.95	300	3.80
100	2.20	400	4.40
125	2.45		

These quantities for the Cincinnati conditions corresponded to an estimated average annual charge of 1.6 grains per gallon of filtered water. During freshets the optimum quantity of chemical, according to Mr. Fuller, may deviate from the given figures by .25 grain. The amount of chemical required, based on three days of preliminary subsidence of the water, he estimates at from 1 to 3 grains per gallon for most days; occasionally periods might be expected when as little as 0.7 grain would suffice, while during other periods much more than 3 grains would be necessary.

The action of the sulphate of alumina is not limited, however, to the removal of turbidity and bacteria; it possesses the property of combining with the coloring matter dissolved in the water, breaking it up, coagulating and precipitating it with the suspended matter. This property is very useful in the treatment of waters which have acquired a dark color from long contact with peat, leaves, grass, roots and decaying organic matter. Slow sand-filters, as well as those of the rapid type, are almost powerless to effect much change in coloring matter of this kind unless the water is first treated with sulphate of alumina. The alum has also the power of uniting to a certain extent with the organic matter in solution in the water, and bringing about a higher chemical purification than ordinary slow sand-filtration, without the alum, can accomplish.

Admission of Chemical Solution to the Water and Time Necessary for Coagulation and Secondary Subsidence.—In the past the practice has varied much in

regard to the proper time and place for the admixture of the solution of aluminum sulphate. Some plants were arranged so that the solution passed into the water as it reached the filters, while in others some time was allowed to elapse between the admission of the alum and the filtering of the water. The practice must necessarily vary in different works, because the object of coagulation is two-fold: to reduce the amount of suspended matter before it reaches the filters, and to catch, in the filter, that which cannot be economically removed by subsidence. With turbid waters, therefore, an economical solution of the problem would be obtained by finding that design for the works in which the combined cost of sedimentation, coagulation and filtration would be a minimum. It is obviously a waste of money to apply a coagulant to a water which contains particles large enough and heavy enough to settle out by themselves in a reasonable length of time—say 24 hours or less. Obviously it also would be a waste of money to apply a chemical for the settlement of water containing a high degree of turbidity, partly of fine matter and partly of coarse, until the coarser had settled out unaided. As already shown in Chapter II., rivers differ greatly in regard to the character and amount of sediment carried in suspension. The economical period of subsidence must, therefore, in each case be determined by experimental work. In a great many plants about 24 hours has been found to be the economical limit for the simple subsidence of the greater part of the suspended matter, the portion

still remaining in suspension settling at a very much slower rate. A portion of this matter still in suspension, after 24 hours' subsidence, will be heavy enough to go down in a few hours when coagulated with other particles. It is apparent, therefore, that a process of simple subsidence, followed by coagulation and secondary subsidence, will relieve the filters of part of the work, saving wash-water, supervision and attendance. Another important point, which was discovered by Mr. Fuller in Louisville, is that clay particles have some faculty of absorbing or holding the sulphate of alumina, so that a larger dose of the chemical may be taken up by the water than is accounted for by its alkalinity. This is another reason for deferring the admixture of the chemical until after the employment of plain subsidence to the economical limit.

So far as the removal of bacteria is concerned, with comparatively clear waters, a long period of coagulation does not seem to be advantageous. This was exemplified in Weston's experiments, and also in the data given by Mr. Fuller in his Cincinnati report. With turbid waters, however, time is of considerable significance, a period of from half an hour to six hours of subsidence greatly increasing the bacterial efficiency. It is absolutely essential that the chemical be applied continuously, and in the proper proportions, in accordance with the changes in character and turbidity of the applied water, and in proportion to the amount passing through the filter. This is the difficult and delicate part of the process.

It requires on the part of the attendants a high degree of intelligence and a conscientious devotion to duty. A failure to apply the chemical for a few minutes even, under some conditions, might be followed by disastrous consequences, which would, in addition to the actual inconvenience and danger resulting, throw discredit on the plant.

Mr. Fuller suggests that if, during the stage of coagulation and subsidence, the charge of chemical be kept a little below the normal, a small additional charge may be introduced as the water enters the filters, thus economically adjusting the dose to the requirements. This is of importance in the maintenance of high efficiency, because with turbid waters there is always a tendency to a reduction of efficiency for a few minutes after washing.

With clear waters, judging from the Providence, Pittsburgh and Cincinnati experiments, it seems desirable to admit the chemical near the filters. When more than an hour was allowed to elapse between the time of admission of the solution and the passing of the water into the filters the results did not seem to be so good.

Effect of Filtering Medium.—A coarse quartz sand, of uniform size of grain, is ordinarily used for rapid sand-filters. As the sand serves only the purpose of arresting the coagulated suspended matter, it may be seen that the finer the sand, within certain limits of practicability, the thinner may be the layer, and the sooner the filter will reach a normal condition in its ability to remove turbidity and bacteria. Of

course, if too fine, clogging will occur immediately, and if too coarse too much water will have to be wasted after putting the filters in service. The sand grains should be as nearly uniform in size as possible so that in washing the bed, by reversing the current, the particles of sand will not be carried away in the wash-water. Incidentally, fine sand offers a greater steadying effect to the flow of the water than coarse sand, and, therefore, reduces somewhat the probability of breaks in the top-surface film and the consequent passage of raw water through the bed. More water is necessary, however, for washing fine sand than coarse; it is also probable that a bed of fine sand will require thorough sterilization and washing with caustic soda at more frequent intervals than one of coarse sand. The usual thickness of bed averages about 30 inches, with coarse sands; by using rather a fine river sand, however, Mr. Fuller obtained satisfactory results at Cincinnati with a depth of 20 inches.

Effect of Rate of Filtration.—Uniform experience indicates that the rate of filtration in rapid sand-filters operated by gravity (providing this rate is uniform and feasible in practice) has very little effect on the efficiency of the process. In filters of the pressure type, however, the case is entirely different, because in these very great heads may be suddenly thrown on the filters, causing the breaking through of the film and a rapid deterioration in the quality of the effluent. This weakness of the pressure type of filters, as ordinarily constructed, is now so well

known that they are now rarely used for the purification of drinking waters, being replaced by the open, or gravity, type, in which the head cannot exceed a certain limit.

When the pressure filters, however, are located between the pumps and a large distributing reservoir, so that the rate of filtration may be maintained quite constant, the pressure type of filter may give very satisfactory results.

At Providence no material difference in efficiency was noticeable with rates of from 116,000,000 to 156,000,000 gallons per acre per day. At Cincinnati at rates of from 46,000,000 to 170,000,000 gallons per acre per day, and at Pittsburgh, with rates from 68,000,000 to 146,000,000 gallons, no decisive differences in efficiency were apparent. It was very noticeable, however, in all these experiments, that the number of bacteria in the effluents fluctuated with the number in the applied water. One point, however, of agreement in all recorded tests, is that the rate of filtration should not be allowed to change too suddenly from a low to a high rate, as such a procedure is followed by the breaking loose and washing into the effluent of some of the bacteria and matter retained in the filter. Properly designed controllers are, therefore, necessary to prevent such fluctuations, while the filtered water should be stored in a reservoir of sufficient capacity to balance the unequal rates of draft. The proper capacity for filtered-water reservoirs is discussed in Chapter VIII., and the remarks made on page 179 regarding the proper height of the

water surface relative to the filters apply equally well in the case of rapid sand-filters.

It is the universal experience that the rate of filtration does not influence the relative amount of chemical necessary for proper filtration. Thus, if one grain per gallon is necessary for a rate of 50,000,000 gallons per acre per day, one grain per gallon is sufficient for a rate of 150,000,000 gallons per acre per day.

Effect of Loss of Head.—In operating a filter plant as much water should be filtered between washing times as possible, due regard being had to economy of operation. If washing is put off too long, however, the additional amount of water passed at the end of the run, per foot of head, will be less than the normal. Therefore, the time when washing should be done will be indicated when the yield per foot of head begins to decrease rapidly below the normal. This is an economical question, however, and does not affect the efficiency of the process, except indirectly by separating, as far as possible, the periods of reduced bacterial efficiency due to washing, and thus to a certain extent increasing the general average efficiency.

Mr. Fuller found at Cincinnati that for rates of 120,000,000 gallons per acre per day, with fine sand, the economical loss of head was about 12 feet, and he concluded that "high rates are more economical than low ones, and that the full head which can be economically used efficiently should be provided. Just where the economical limit of the rate of filtra-

tion is can only be determined from practical experience with a wider range of conditions than existed here, but there seem to be no indications that the capacity of a plant originally constructed on a medium-rate basis (100,000,000 to 125,000,000 gallons per acre daily) could not readily and economically be increased, as the consumption demanded, to rates at least as high as the highest tried here (170,000,000 gallons per acre daily), provided the full economical increase in loss of head could be obtained."

Negative heads with this process are practicable, and, according to Mr. Fuller, desirable if the section of greatest resistance is located at the throats of the strainers instead of in the sand layer. The liberation of the dissolved air, if any, will then occur below instead of in the sand layer where clogging is taking place, and it will then not have a tendency to reduce the capacity of the filters, as has been the case when slow sand-filters were operated under negative heads.

Effect of Washing Rapid Sand-filters.—Rapid sand-filters, after several hours of service, gradually clog up so that the yield of filtered water begins to diminish. When this time comes they are washed by reversing the direction of the current of water through them, at the same time agitating the sand in such a manner that the dirty gelatinous coating on the surface of the filters and on the grains of sand is washed off and carried away. It has been observed that after washing the number of bacteria in the effluent is considerably increased, for a period varying from a few minutes to about three hours. It has generally

been the practice, therefore, to allow the first water passing through after washing to run to waste. Mr. Fuller, as the result of his Louisville and Cincinnati experiments, holds the opinion that where the coagulant is properly applied and the washing is properly done, it is unnecessary, at moderate rates of filtration, to waste any of the water after washing, as the reduction of general efficiency following the discharge of this small amount of water not quite so good as the average, would not be felt in a large plant composed of several units, only one of which, perhaps, might be washed at one time.

After filters have been in service for several months their bacterial efficiency generally runs down, and even washing will not restore them to their best condition. Mr. Weston found at Providence that after about six months it was necessary to wash out the filters with caustic soda in order to place them again in a condition of normal efficiency.

Effect of Trailing.—When filters have been in service for several hours, and surface clogging has reduced their capacity somewhat, an expedient called trailing is sometimes resorted to. This consists of scoring the top surface of the sand in concentric rings or symmetrical patterns to break the continuity of the surface film, and thus increase the yield of the filter. The effect of this treatment, as reported from the Pittsburgh experiments, if the sand is coarse, is to increase the yield, at the expense of purification, while if the sand is fine the detrimental effect, in point of purification, is less noticeable. The

effect on the yield is not, however, always easy to foretell, as with some waters the particles of suspended matter may be carried down so far into the filter that surface agitation will not loosen up the material enough to increase its permeability. Where the particles are coarser and are, therefore, retained nearer the top, surface agitation may be more effective.

CHAPTER VI.

THE CONSTRUCTION AND OPERATION OF RAPID SAND-FILTERS.

Up to the present time rapid sand-filter plants have been erected by one or another of several companies controlling patents on the processes and on the various parts of the different makes of filters. The fundamental patent covering the continuous application of a coagulant in connection with rapid sand-filtration has now expired.

The city of Louisville, Ky., taking advantage of the lapse of this patent, has prepared plans for rapid sand-filters of different design from any heretofore constructed.

The various commercial types of rapid sand-filters differ from one another principally in the means used for adding the chemical to the water, in the strainer system for retaining the sand, in the manner of washing the sand, in the manner of regulating the rate of filtration, the method of accomplishing coagulation, and the method of admitting the water to the filters.

Gravity and Pressure Filters.—Rapid sand-filters are built of two types, gravity and pressure. As has already been stated, the gravity type is now used al-

most exclusively for water-supply purification, the pressure type being more liable to derangement and, unless placed between the pumps and the distributing reservoir, less reliable in point of efficiency. The pressure type may always find application, however, in manufacturing processes where the removal of the extremely fine clay particles is not essential.

In general, the filters are tanks of steel, iron, or wood, containing in their bottoms systems of pipes for drawing off the filtered water. To prevent the sand from escaping with the water, strainers of brass-wire cloth of fine mesh, brass plates or cones bored with small holes, or slotted plates or rosettes, have been employed. The sand layer is usually from about two and a half to three feet thick; the sand is of rather coarse grain, quite uniform in size, and the piping is so arranged that the water may be admitted to the top of the filter and taken away, after filtration, from the bottom. Overflows are also provided, in the gravity type, as well as a connection by which the fitered water may be forced back through the filter for washing the sand. Arrangements are also made to permit the wasting of the water, upon placing the filter in operation after washing, until the surface film has again formed. The washing arrangements, in the gravity type, generally consist of arms, or rods, that can be lowered down into the sand. The rotation of these arms, combined with the upward motion of the wash-water through the sand, loosens up and scours off the deposits of dirt and coagulant which have formed around and between the sand grains. Other

methods of washing are described on subsequent pages.

In the plans for the Louisville plant the filters, instead of being in small circular units, are rectangular and comparatively large in area. They have sides and bottoms of concrete instead of sheet metal or wood. The bottoms also, instead of having a system of pipes and strainers for carrying away the filtered water, have layers of brass-wire cloth supported on a framework of iron in such a manner as to form a hollow floor under the whole filter area.

A perspective view showing the construction and arrangement of a Jewell subsidence gravity filter is shown in Fig. 37. In this type of filter the influent water enters the subsidence tank in a direction tangential to the periphery, in order to give a rotary motion to the water in the tank, by which the speed of coagulation may be hastened. The water is admitted upon the surface of the sand through the central vertical pipe, and is drawn off after passing through the sand through the delivery valve, 5. After passing through the controller, 7, it goes to the filtered-water reservoir. The filter is washed by revolving the rakes or agitators, at the same time forcing filtered water upward through the strainer system, by closing valves 1, 2, 6, 3 and 5, and opening valve 4. After the washing has been completed, valve 4 is closed and valves 1 and 3 are opened, permitting the filtered water to run to waste until the filter is again in the proper condition.

Filters of this type are in use, among other places,

in the recently completed plant at East Albany, N. Y. A photographic view of the interior of this plant is given in Plate XV.

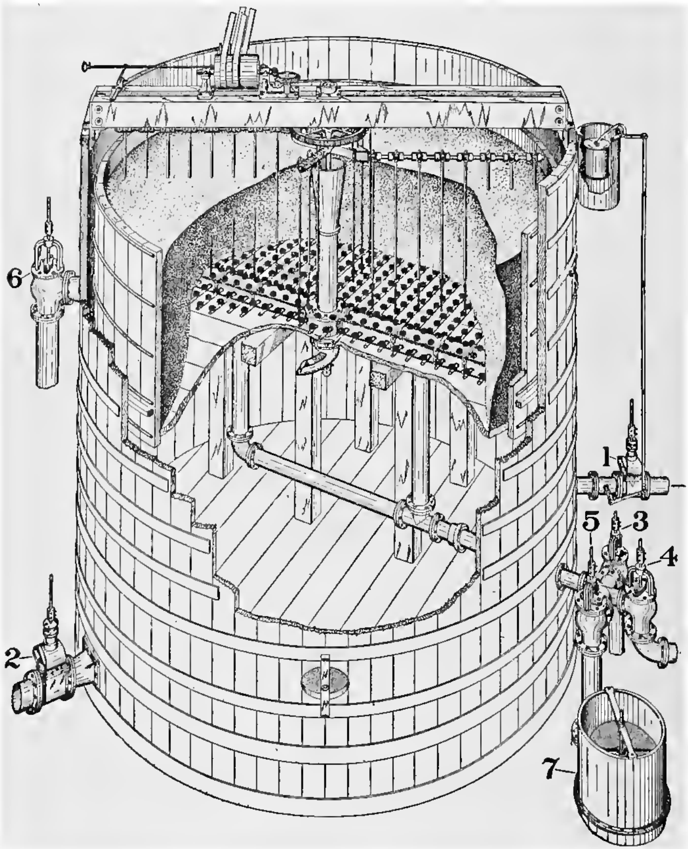

FIG. 37.—SECTIONAL VIEW OF A JEWELL SUBSIDENCE GRAVITY FILTER.

In the Continental filter, which is shown in Figs. 38 and 39, the washing is done by compressed air and

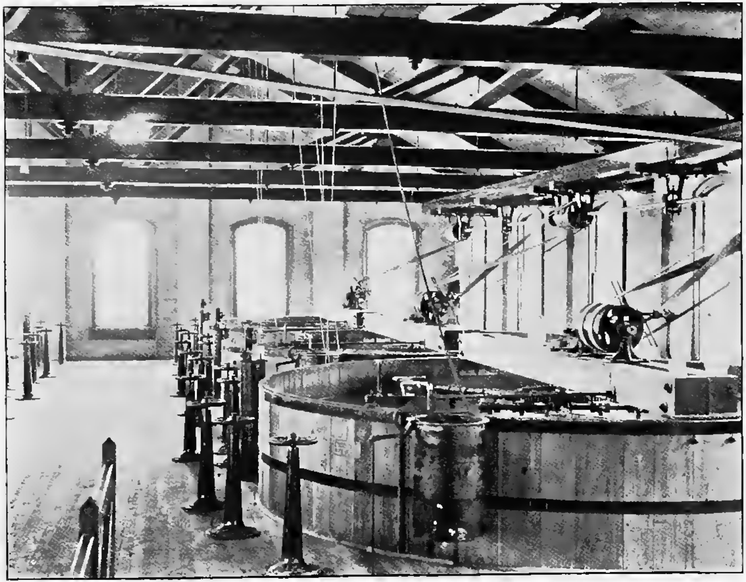

Plate XV.—View of the Interior of the East Albany, N. Y., Filter Plant.

wash-water used alternately. Other features of this design are the covering of the strainer system with a layer of gravel, and the distribution of the raw water over the surface of the sand by a trough extending

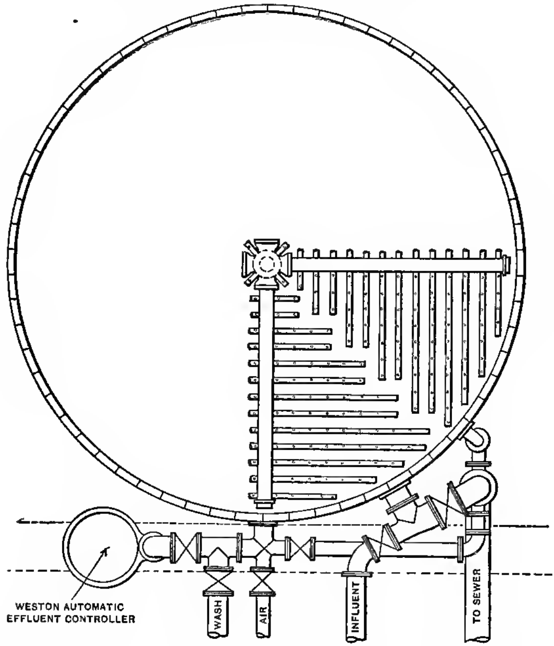

FIG. 38.—PLAN OF A CONTINENTAL GRAVITY FILTER WITH AIR WASH.

around the inner edge of the filter and out over the top of the sand in the shape of a cross, in order to distribute the water evenly over the sand at a very low velocity.

The New York sectional wash gravity filter is shown in Fig. 40. In this type of filter the central

valve is so designed that the wash-water may be forced through only one section of the filtering sand at a time. By this means more thorough scouring of the sand grains is accomplished than if the whole filter were washed at once. The water is admitted to

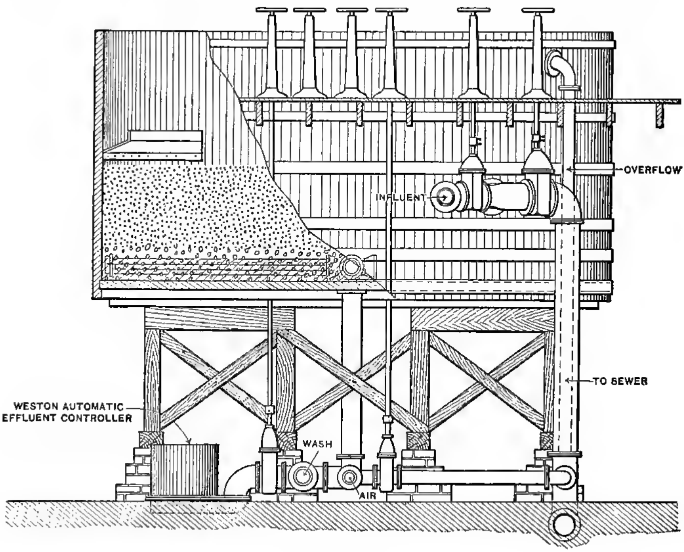

FIG. 39.—SECTIONAL ELEVATION OF A CONTINENTAL GRAVITY FILTER WITH AIR WASH.

the filter through a set of perforated pipes supported above the sand level. In Fig. 41 is shown the New York sectional wash pressure filter.

There are several other makes of rapid sand-filters in use for the filtration of municipal water-supplies, but the general principles underlying the design of such are sufficiently well illustrated in the types above described.

Introduction of Chemical Solution.—The sulphate of alumina should be of a high grade, as the slight economy resulting from the use of low grades is not warranted by experience. Customers frequently buy the sulphate on the basis of the amount of AL_2O_3 it

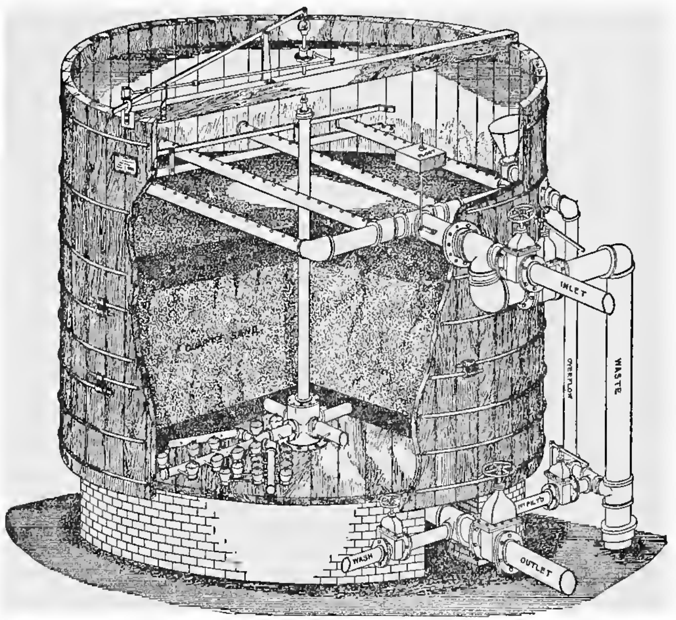

FIG. 40.—SECTIONAL VIEW OF A NEW YORK SECTIONAL-WASH GRAVITY FILTER.

contains, the usual proportion being about 17½ per cent. Grades containing as low as 12 per cent. have been used successfully, but in these the insoluble compounds, mostly silicates, tend to foul the pipes and orifices, making their cleansing necessary more

frequently than if a high grade were used. The mixing tanks are generally of wood, of sufficient capacity to hold six hours' supply of the solution. The

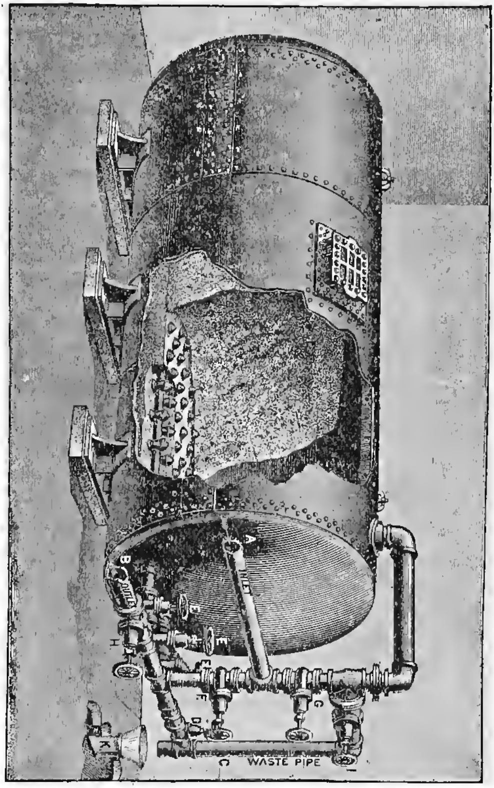

FIG. 41.—SECTIONAL VIEW OF A NEW YORK SECTIONAL-WASH PRESSURE FILTER.

requisite quantity of alum is placed in a crate or box near the top of the tank, and a small stream of water is sprayed upon it, percolating down through the alum and falling into the tank. The flow of the

stream can be so regulated that by the time the tank is filled the alum will all be dissolved. The solution is kept in agitation by stirring with mechanical devices, or by compressed air forced up through the bottom. Two tanks should be provided so that the solution may be in preparation in one while being drawn from the other. The alum solution goes from the solution tanks to the measuring tank, from which it in turn flows into the filter inlet pipe. A typical measuring tank, for use with gravity filters, is shown in Fig. 42. The depth of the solution over the ori-

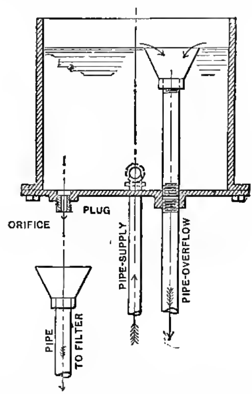

FIG. 42.—SECTION OF A TYPICAL ALUM SOLUTION MEASURING TANK FOR A GRAVITY FILTER.

fice in the bottom of the tank is kept uniform by providing an overflow through which the surplus may flow back to the solution tanks. If the solution flows to the measuring tank by gravity, the overflow is pumped back to the solution tanks. The dose of the solution is varied, in accordance with the char-

acter of the water, by changing the size of the orifice or by changing the strength of the solution.

A type of measuring tank for use with pressure filters is shown in Fig. 43. In operation this tank is first filled with a known quantity of potash alum.

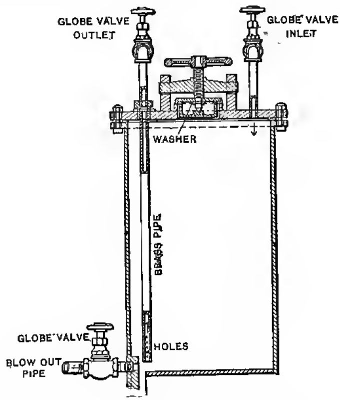

FIG. 43.—SECTION OF AN ALUM SOLUTION TANK FOR A PRESSURE FILTER.

A small stream of water is then admitted through the inlet. The water passes down through the alum, dissolving it, and then up through the outlet pipe and into the influent pipe to the filter. The pressure required to cause this flow is about ½ lb. per sq. inch above the pressure as the water enters the filter. This is produced by throttling the influent pipe between the two connections with the tank. An apparatus is sometimes used in connection with this tank, to vary the dose of solution in proportion to the flow of water to the filter. Great accuracy, however, is not claimed for such regulation.

In large gravity plants the addition of the chemical solution may conveniently be accomplished (as proposed for the Little Falls plant for the East Jersey Water Co.) by providing a plate in the bottom of the measuring tank, the plate having an orifice for each filter, and each orifice having the same area as the others. By having several of these plates, the orifices in each plate having a different area from those in the others, the dose of chemical may be varied in accordance with the character of the water. Further regulation of the dose may be accomplished by having the solution made up in one, two, three or four per cent. mixtures, and thus save multiplication of plates. If a filter is out of service an orifice is closed and the dose of chemical will thus always correspond with the amount of water going to the filters.

In place of having a gravity feed the chemical solution is sometimes pumped into the influent pipe. A successful pump for this purpose is illustrated in Fig. 44. A small propeller wheel is mounted in a section of the influent pipe, and a bevel-gear wheel on the shaft of the propeller turns a small shaft which carries the crank driving the pump. The pump is made of hard rubber and is mounted on the pipe. The chemical solution is drawn from the solution tank by the pump, and forced into the influent pipe. This apparatus must work very freely in order to be successful; in fact its work should be limited merely to measuring the quantity of solution. It is also necessary to restrict the section of the influent pipe so that the velocity at the propeller will be at least six

feet per second, otherwise the velocity head will not be sufficient to work the apparatus. The pump should always be kept very clean, and therefore a

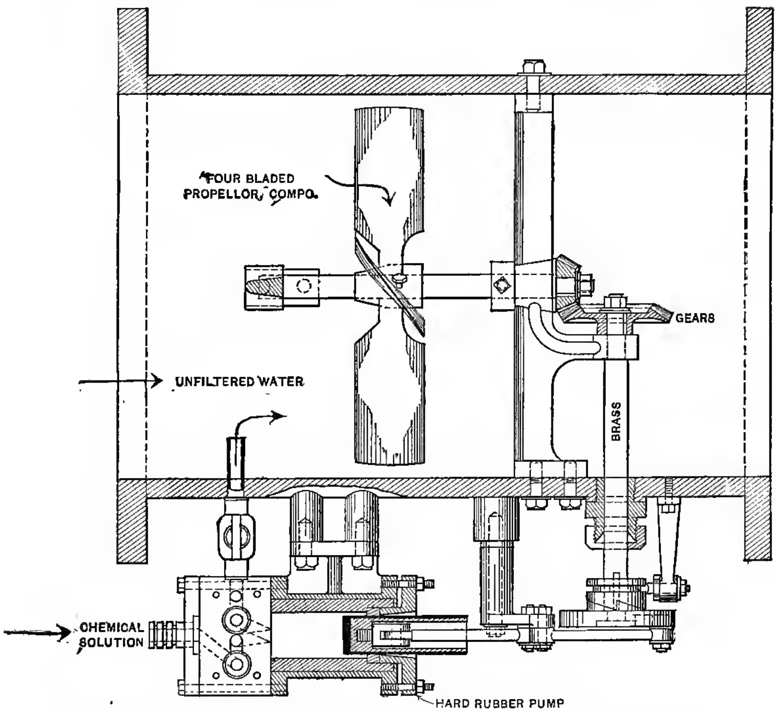

FIG. 44.—SECTION OF AN ALUM SOLUTION PUMP FOR EITHER A GRAVITY OR A PRESSURE FILTER.

high grade of sulphate of alumina is desirable when this apparatus is to be used. This system of chemical feed may be used with either the pressure or gravity type of filter.

All the piping in connection with the chemical feed

should be of brass or of lead. Lead pipe gives less trouble with clogging than brass, and its length of life is also greater, the brass pipes lasting about ten years.

Regulating Apparatus.—The controller designed by Edmund B. Weston, C.E., is shown in Fig. 45 and is described by him as follows:*

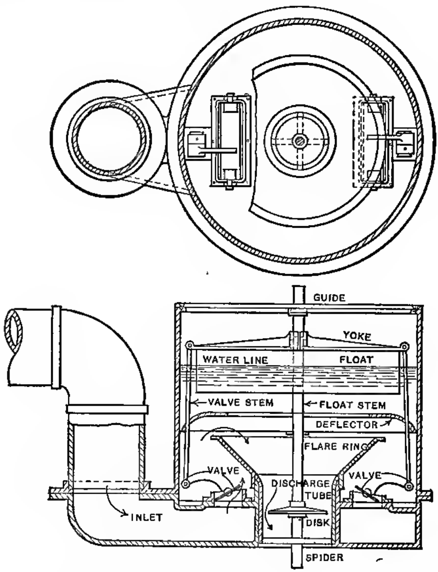

FIG. 45.—SECTION OF WESTON'S AUTOMATIC CONTROLLER.

"The necessity of an automatic controller for measuring the flow through a filter-bed and keeping

* The Norfolk, Va., Filter Plant. Paper by E. B. Weston read before 20th Annual Conv. Am. Water-works Association, at Richmond, Va., May 16, 1900.

it perfectly constant during the process of filtration, is of the utmost importance.

"The two principal reasons for the necessity of an accurate controller are:

"1st. The exact quantity of water passing through the filter-bed being known, the correct quantity of sulphate of alumina solution can be accurately and uniformly applied to the raw water, by gravity or other means.

"2d. By keeping the flow of water through the filter-bed perfectly constant, scouring action in the filter-bed is avoided.

"The controller is connected (outside of the filter) to the draft or delivery pipe of the filter, from which the filtered water passes through butterfly valves in the lower part of the controller. The controller contains a float mounted on a hollow float-stem, operating in guides at the top and bottom of the controller. Beneath the float is a deflector, designed to quiet the incoming water and reduce any currents, thereby giving a smooth entrance to the discharge tube, and being aided in this respect by the flaring ring at the top of the discharge tube. Mounted also upon the float-stem at a fixed distance below the float, so as to be maintained at a constant depth, is a disc which is turned with a thin edge and sharp corners and of such a diameter as will give the annular orifice, between the disc and the walls of the discharge tube and which rises and falls with the float, a predetermined area proportional to the desired rate of discharge. The float being mounted at a fixed distance from the disc,

thereby maintains a constant head of water upon the movable annular orifice. The inlet butterfly valves in the lower part of the controller are operated by levers connected to the float, so that the rise and fall of the latter tends to close and open them.

"The regulation of the flow of water through the filter-bed may be described as follows: With a given head of water upon the surface of the filter-bed and a free discharge from the filter, the rate of discharge will vary with the condition of the filter-bed. If, for a given level of water in the controller, the head on the inlet pipe be such that more water will pass through the inlet butterfly valves than can be discharged through the annular orifice, the level of the water in the controller will rise, and with it the float, which will tend to close the inlet butterfly valves and throttle the flow so that equilibrium is established between the supply to and the discharge from the controller. If, on the other hand, the head on the inlet pipe be reduced, and consequently the flow through the butterfly valves, the water level in the controller falls and the float falling with it increases the opening of the valves and thus restores the equilibrium. Should the head on the inlet pipe be reduced below that determined by the minimum limit, the water level in the controller will fall below the minimum limit, the float will be submerged less, and consequently the head on the annular orifice and discharge tube will be diminished below the minimum desired. This will indicate a needed washing of the filter-bed, which is manifested at Norfolk by an indi-

cating water gauge, that is actuated by a float in a vertical pipe which is connected to the inlet pipe of the controller. The rated capacity of discharge may be adjusted by altering the depth of submergence of the disc, or by changing the area of the annular orifice by substituting a disc of different size. Air is admitted below the disc through the hollow float-stem, which has vents below the disc.

"Tests have been made with this design of controller under heads ranging from 0.33 to 18 feet, and have not shown any practical measurable variation in the discharge."

Washing Arrangements.—In many of the existing filter plants it is difficult to wash the sand near the bottom and between the strainers, and the more or less polluted water in this unwashed sand is apt to affect the quality of the effluent. The floor of the Louisville filters is designed to correct this by permitting all parts of the area to be washed alike.

The stirring arms for the Louisville plant will be mounted on a travelling platform suspended over the beds on rollers, and capable of being raised or lowered or transported sidewise. This will permit one apparatus to serve the filters of the whole plant.

In Plate XVI is shown the agitator used in the Jewell filter at the Pittsburgh experiment station. The rods are pivoted to the arms in such a manner that when revolving in one direction they will stand vertically and stir up the sand. When revolved in the reverse direction they assume an inclination of about 60 degrees from the vertical, so that their ends

PLATE XVI.—AGITATOR OF JEWELL FILTER. PITTSBURGH EXPERIMENT STATION.

rest upon the surface of the sand. A short chain is attached to the end of each rod, as may be seen in Fig. 37.

The agitator used in the Warren filter is shown in Plate XVII. The stirring rods in this apparatus are movable vertically by a hydraulic lift supported above the filter.

In large plants the filters may be washed by forcing air upward through the sand-bed. The air is delivered at the filters under a pressure of about 3 lbs. per square inch, by rotary blowers. On reaching the strainers the air expands and lifts the bed of sand and superincumbent water sometimes to a height of two or three inches. The bubbles of air carry the sand grains upward with considerable force, rubbing them together, scouring them quite effectively, and floating them about through the entire depth of water above the sand. Mr. Charles L. Parmelee, Chief Engineer of the New York Continental Jewell Filtration Company, has seen grains of sand thrown into the air above the surface of the water, by bursting bubbles, when the water stood six feet in depth over the normal sand surface.

Air-washing has been in use since 1896 in pressure filters, and since 1898 in filters of the gravity type, and is said to be as effective as the agitation of the sand with rakes, combined with the usual water-washing process by reversal of current.

In washing with air the air and wash-water are used alternately. If the air and water are used together considerable sand will be carried away with

the wash-water. The amount of power required for air-washing is said to be about the same as for agitation with rakes, but the amount of wash-water required is about half as much with air as with the rakes.

The air system, however, on account of the expense of installation, is not used in small plants. Its chief advantage in large plants comes from permitting the use of rectangular filters.

Air-washing in large plants is now considered quite satisfactory. Its use has been recommended in the large filter plant, for which plans were recently prepared, to be erected at Little Falls, N. J.

Cost of Rapid Sand-filters.—Data on the cost of existing rapid sand-filter plants are not valuable for comparisons, because of the included values of patent rights and other expenses incident to the business of private companies. With the expiration of the fundamental patent, however, it becomes a simple matter to design a plant and estimate its cost. In the general run of large plants, with circular filters, the cost has been at the rate of probably about $500,000 per acre of filter surface, excluding the cost of buildings, foundations, pumping machinery, land, etc., or, in other words, they have been about ten times as expensive as covered slow sand-filters of the same area. As, however, the rapid sand-filters pass the water at a rate many times faster than the slow filters, the relative cost of construction, per unit of water filtered, is really only about from one third to one fifth as great for the rapid as for the slow sand-filters. With im-

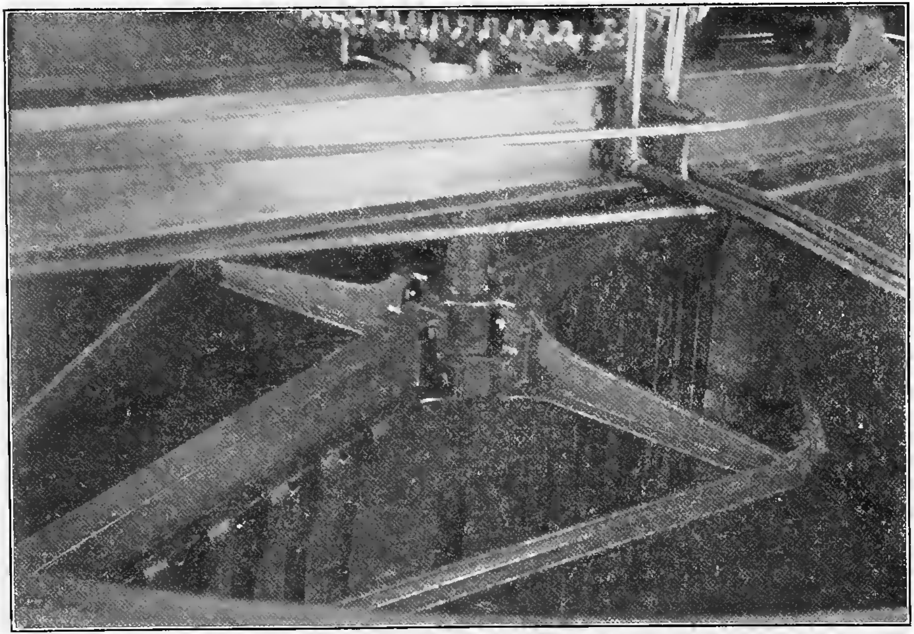

Plate XVII.—Agitator of Warren Filter. Pittsburgh Experiment Station.

provements in design, in the matter of larger units, steel and concrete construction, economy of space and piping resulting from the use of rectangular filters, improvements in sand-washing devices, etc., the cost of construction and of operation of rapid sand-filter plants may be brought still much lower. Cheapness of installation and efficiency, combined with economy in operation, are the greatest points to attract favorable attention. When improvements, along the lines suggested above, have been perfected, there is no doubt but that rapid sand-filters will find a more extensive field of application in the future for the purification of drinking waters.

When constructed in small circular units they also offer an advantage in another direction, which was first noted in Philadelphia, in the report of the Mayor's Expert Water Commission. A filtered supply from the Schuylkill and Delaware Rivers was recommended. The Schuylkill, on account of its small flow, could not be depended upon to furnish sufficient water for supplying the entire district through which it passed, when, in the future, the population should increase beyond a certain limit. As the filter plants in the upper portion of the city would always have to depend on this stream for water, it was recommended that the one lowest downstream be made a rapid sand-filter plant composed of small units, so that in the future, when all the water of the river was needed for the upper plants, the lower site could be abandoned and the filters be moved over to the Delaware River. This

plan would entail less loss than the abandonment of an expensive slow sand-filter plant.

Operation.—The water after having been treated with the coagulant from the supply tank, by means of an automatic feed which secures the delivery of a quantity of alumina in proportion to the amount of water entering the filter, passes into the settling basins where coagulation takes place and a certain amount of the suspended matter may be precipitated. An energetic agitation of the water, after adding the chemical solution, materially hastens the process of coagulation, thereby permitting the use of smaller settling basins.

When a filter is clean the resistance to the passage of the water through the sand layer is much less than after it has been in service for a while and the rate of filtration, with a constant head, would, therefore, gradually decrease. In other words, at first it would filter the water too rapidly. In order to regulate this speed, automatic devices, called controllers, have been devised. These regulate the speed to a predetermined rate, thus making the action of the filter regular and uniform. After the available head has been used up the filter must be washed. The controller devised by Mr. Edmund B. Weston has already been described.

Period of Time Between Washings.—The length of time between washings, at the Cincinnati experimental plant, with fine sand in the filters, ranged from 8 to 24, and averaged 15 hours, while with the coarse sand these periods became 6, 36 and 20

hours, respectively. The general average for several plants of which the author has secured records seems to be about 16 hours. The coarse sand in the Cincinnati experiments could be washed in about 20 minutes, while the fine sand required 30 minutes. In Mr. Weston's Providence experiments the average time of washing was about 11 minutes, and the water was wasted for 30 minutes after washing. At the Pittsburgh Experiment Station the quality of the effluent was below the standard for about 20 minutes after washing, and it was, therefore, found advisable to waste about 2 per cent. of the filtered water.

Lost Sand.—A certain amount of sand, depending upon the judgment of the operatives, the fineness and uniformity coefficient of the sand and the velocity of the wash-water, will be wasted or lost in washing the filters. An allowance of about 3 inches in depth, per annum, would probably not be excessive with such sands as are commonly employed. The lower the uniformity coefficient the less will be the loss from this cause.

Labor for Operation.—The labor necessary for operating a rapid sand-filter plant is a small part of the cost of operation, varying from 12 to 20 per cent., usually, of the total cost. In a plant in one of our southern cities having 22 pressure-filters, with a daily average capacity of 3,000,000 gallons, the filters are run by two men at salaries of $60 and $40, respectively, per month. For a larger plant, say of 50,000,000 gallons daily capacity, the force would

probably consist of three shifts of engineers and firemen and three shifts of laborers of four to each shift. The same force could take care of a larger plant. A plant of 100,000,000 gallons daily capacity could probably be run with three shifts of engineers and firemen and three shifts of laborers of six to the shift, providing the filters did not require washing oftener than once in eight hours, could be washed in 30 minutes to the filter and were in units with a daily capacity of not less than 1,000,000 gallons each.

Wash-water.—The normal rate for operating rapid sand-filters is from about 100,000,000 to 150,000,000 gallons per acre daily, the filters being allowed to run until they become so clogged that the allowable loss of head is consumed. As already stated, they are washed by pumping or forcing filtered water back through the underdrains at a rate from three to four times as great as that at which the filters operate normally, at the same time agitating the sand beds with revolving arms. They are also sometimes scoured by sectional washing, or by using compressed air and wash-water alternately. The quantity of wash-water required will depend upon the size of the grains of sand, the character of the raw water and the amount of clogging. At Cincinnati, Mr. Fuller found that from 4 to 9, and averaging 5 per cent. of the filtered water was required for washing with the fine sand, while from 2 to 6, and averaging 3 per cent. was needed with the coarse sand-filters. In the Providence experi-

ments Mr. Weston found that 4.9 per cent. of the filtered water was needed for washing the sand and that it was necessary to waste about 2.9 per cent. on starting the filters in operation after washing. Mr. Fuller, in his Cincinnati report, states that with proper manipulation no wastage of wash-water was necessary, as it could be pumped back into the subsiding reservoir, where the great bulk of the bacteria and suspended matters would be deposited by plain subsidence in less than one day. He also states that although the quality of the filtered water was inferior to the normal directly after washing the filters, the evidence indicated that in a large plant it would not be desirable or necessary to waste any filtered water.

CHAPTER VII.

CONCLUSIONS.

General.—Leaving out the question of household filters, which has no place in a work of this character, we are now in a position to summarize the knowledge thus far gained by experience with the purification of water by filtration on a large scale. Generally speaking, there are only two principles upon which municipal filter-plants have been successfully designed in this country. In one type the water is filtered slowly, through beds of sand, without the use of chemicals to aid the process; in the other the water is filtered rapidly through beds of sand after a coagulating material has been introduced into the water. In slow sand-filters the most usual rate of filtration is about 3 million gallons per acre per day; in other words, the water passes down through the sand in a coumn having the full area of the filter and a depth of about ten feet. In rapid sand-filters the rate of filtration is from 30 to 50 times as fast. The slow type is suited for the purification of polluted waters not too highly colored by vegetation and not carrying too great an amount of finely divided suspended matter. The rapid type is more suited for the removal of turbidity and color; when carefully operated rapid sand-filters can give a very high efficiency, but sufficient experience has not

yet been had to warrant the unqualified statement that they are ordinarily as safe as the slow filters, in the treatment of a sewage-polluted water. Operating at high rates, a break in the regularity of management would be likely to cause a great degree of deterioration in the effluent; and further, filters of the rapid type are not suitable for the economical treatment of very soft waters.

There are undoubtedly situations where a combination of slow and rapid sand-filters would prove economical, for instance, near the line of latitude where is it doubtful whether or not it would be economical to cover the filters. In such places a combined plant, if circumstances permit, might work out satisfactorily. The rapid filters could be relied upon mostly in cold and the slow ones in warm weather, each serving at the period of the year when the condition of the water, as to pollution, is best suited for the respective type, thus saving the cost of roofing over the slow sand-filters. The relative areas of slow and rapid filters would have to be determined from a special study of the prevailing meteorological conditions. A combination of slow and rapid sand-filters would not prove of benefit in the clarification of turbid waters, because while first passing through the rapid filters the coagulant would abstract finer matter from the water than could be removed subsequently in the slow filters; but in the case of a very highly polluted water double filtration, first through rapid,and then, after aeration, through slow sand-filters, the essential conditions for the proper

action of the two processes being always kept in view, might be preferable to double filtration through slow sand-filters, as has been sometimes recommended. With a turbid, sewage-polluted water conditions might sometimes arise that would make it advisable to use sedimentation and then slow sand-filtration, finishing with rapid sand-filtration in order to remove the last traces of turbidity. Where the water is occasionally too turbid, or contains too much color to be successfully treated by slow sand-filtration, but still ordinarily is of suitable character for treatment by this process, it may be necessary, at times, to precede filtration by sedimentation, with, or, perhaps, without, the aid of a coagulant.

The essential condition for the satisfactory and safe operation of the rapid type of sand-filters is that the dose of coagulant be continuously and properly applied. This necessitates the occasional, or, in some cases it might be more properly said, constant examination of the raw water for turbidity and alkalinity. A failure to apply a sufficient amount of chemical would be followed by reduced bacterial efficiency, and an overdose might be followed by the acidulation of the water with its attendant evils of corrosion in the street-mains and service-pipes. For this reason it is evident that the rapid type is better suited for large cities, where the plant would be of sufficient extent to afford the constant services of a competent chemist, than for cities too small to afford chemical supervision. Of course, in some places, where removal of turbidity is the only object, the services of a chemist could be dispensed with if stand-

ards of turbidity and the accompanying quantity of chemical solution were once established; but in waters polluted with sewage, and varying in alkalinity at different stages of flow and periods of the year, safety from one extreme or the other can only be assured with the services of a chemist.

On the other hand, the slow sand-filters do not generally require such careful attention. If the regulating apparatus is properly designed, so that the filters cannot be operated at too high a rate, there is little concerning the efficiency of the filters that will depend upon the faithfulness of unskilled laborers.

The cost of installing a covered slow sand-filter plant, to filter a given quantity of water daily, is from three to five times as great as the cost of a rapid sand-filter plant of the same capacity. The annual cost of operation, however, is about the same, the cost of the chemical solution, and greater allowances for deterioration, making up for the lower interest charges in the case of rapid sand-filters.

A few words concerning certain methods of water-filtration in use in foreign countries seems to be appropriate at this point.

The Anderson Process.—The Anderson process of water-purification, which has found considerable application in Europe, is somewhat akin in principle to the process of rapid sand-filtration. The process consists of the filtration of the water through beds of sand after a coagulant has been introduced into the water. This coagulant is ferric hydrate, produced by agitating filings and chips of iron in the water.

Some of the iron is taken up in solution, and afterward, on exposure to the air, again passes out of solution in an insoluble flocculent form; this is removed, together with the other impurities, by sedimentation and filtration. The first large Anderson plant was built at Antwerp. Later plants have been installed at Choisy-le-Roi, near Paris, and at Boulogne-sur-Seine. The objects of using the coagulant are to remove turbidity and reduce the area necessary for filtration. The iron process is not of use for removing the stain due to dissolved peaty matter, because the iron will form a soluble compound with the organic constituents of the coloring matter. Aluminum sulphate has been found to be the best chemical for this purpose.

Pasteur-Chamberland Filters.—The best-known porcelain or artificial-stone filters are the Pasteur and the Fischer, or Worms, filters. The Pasteur filtering medium consists of hollow unglazed tubes of porcelain through which the water is forced. The grain of the porcelain is so extremely fine that the bacteria are retained on the surface of the tubes. A Pasteur plant of considerable size has recently been installed for the municipal supply of Darjeeling, India.

Worms Filter.—The Fischer, or Worms, filters are similar in principle to the Pasteur, in that they depend upon the surface of the filtering medium for the retention of the bacteria, without the action of a coagulant or of the nitrifying organism. The slabs of artificial stone, through which the water is passed, are made of sand, silicate of lime and soda,

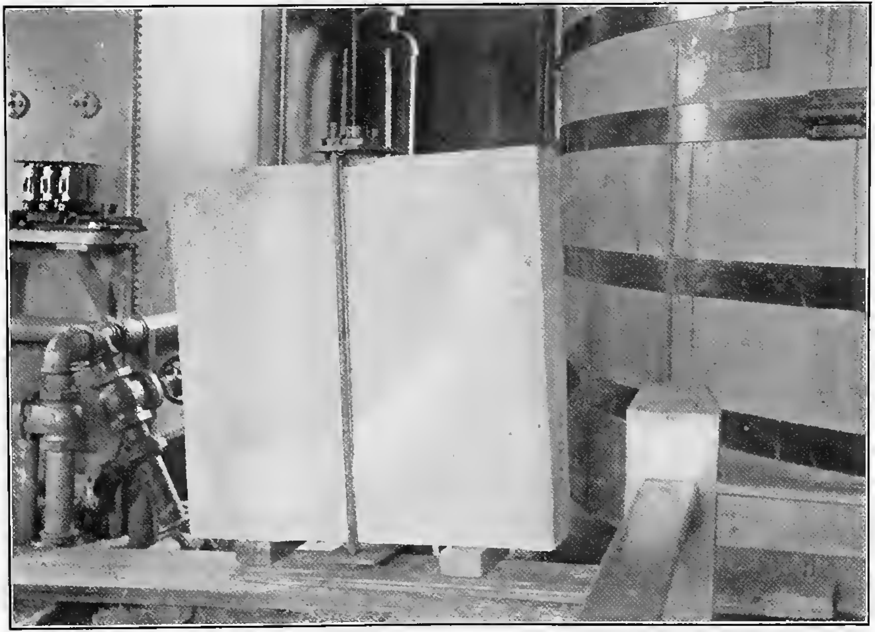

Plate XVIII.—Fischer or Worms Plate, ready to be placed in the Filter. Pittsburgh Experiment Station.

PLATE XIX.—BROKEN FISCHER OR WORMS PLATES, SHOWING INTERIOR CAVITY. PITTSBURGH EXPERIMENT STATION.

moulded into squares about $3\frac{1}{2}$ feet on a side. They are placed in pairs, with their concave sides together, and the water filters through to the inside space, while the dirt is left on the outside. They are cleaned by forcing steam through them in the reverse direction. The largest cities using these filters are Worms-on-the-Rhine and Arad, Hungary.

There are numerous other filters of this type, but so far as the writer knows none of them has been used for municipal supplies. Both the Pasteur and Fischer types of filter can produce good results in the filtration of waters of certain kinds, but it is not settled that they are practicable of installation in the United States, because of cost of construction, cost of operation and lack of sufficient experience with them to determine, in the treatment of our waters, their durability and the cost of replacing breakage. In Plate XVIII is given a view of a Fischer plate ready to be placed in position in a filter at the experiment station at Pittsburgh, Pa. An idea of the construction of these plates may be gained from Plate XIX, which shows two units broken at the same station.

Regarding the Maignen filters, in which a layer of asbestos is spread over the surface of the sand, it is sufficient to say that at the present time the system is not in use in the United States for the purification of a municipal water-supply.

It is hoped that when these different processes may have been tried on a large scale in this country the results of such trials may be recorded in future editions of this work.

CHAPTER VIII.

FILTERED-WATER RESERVOIRS.

Location.—When the filtered-water reservoir is to be near the filters it should be located in a position to which the water from all the filters may be conducted with the minimum length of piping. It should also be constructed, as stated on page 179, at such an elevation that the highest water level can not limit the filtration head.

Shape.—Reservoirs are usually made rectangular in plan when the topography of the ground does not require another shape. Circular or polygonal reservoirs are more difficult to roof than the rectangular type, and hence are rarely chosen when the rectangle is possible. While the quantity of masonry in the side-walls in such is less than in any other shape, the constructional details of roofed reservoirs may counterbalance this advantage. An example of the covered circular type is to be seen at Arnheim, where the vaulted roof is carried on iron posts and girders.

The reservoir should be divided into two or more independent basins by heavy cross-walls. Gates controlling openings through these cross-walls will fur-

nish communication between the different basins. Each basin should have an independent junction with the inlet pipe for filtered water, with the outlet pipe, and also with the overflow and drain pipes.

Circulation.—To prevent the water in the reservoir from becoming stagnant, caused by some of it not being able to escape from the remote corners, the expedient is sometimes adopted of dividing the reservoir by partition walls into a number of narrow parallel channels, each connecting with the next at alternate ends, thus compelling all the water to move in a continuous direction toward the outlet. The filtered-water reservoirs at the Lake Mueggle works, Berlin, are built in this way, and also the large reservoir for spring-water at Frankfort-on-the-Main.

Capacity.—In very many of the European filter plants the filtered-water reservoir is too small to have any effect as a balancing reservoir; the compensation for hourly and daily fluctuation being made by operating the filters at a higher rate to meet the demand. It is needless to say, however, that such a practice, unless properly understood and carefully watched, is not conducive to high efficiency. With clear waters, nearly free from bacteria in their natural state, the danger of reduced efficiency by increasing the rate abnormally is much less than with water more polluted, and, therefore, with comparatively pure waters the storage may be less than with polluted waters.

The capacity of the filtered-water reservoir at

Hamburg is about 6.2 per cent., and at Berlin (Lake Mueggle) about 5.6 per cent. of the average maximum daily draft. Since water even after very careful filtration still contains a small number of bacteria which have passed through the filter, and also a small amount of food matter, it is essential that it should be delivered to the consumer as soon as possible in order that its quality may not deteriorate by the growth of these micro-organisms during storage. This consideration indicates the desirability of a small reservoir. On the other hand, if the filtered-water reservoir is to provide the only storage, a certain amount of reserve is desirable in case of fires, unless a separate supply is provided for that purpose, or a by-pass arranged so that in such an emergency the unfiltered water can be turned directly into the mains. This plan, where the water is treated more to remove turbidity or color than specific bacteria of contagious diseases, is often feasible. Some authorities contend that the plan is safe in all cases, because the infection likely to arise from such occasional delivery of raw water will be less than the total infection resulting from the secondary growth of the bacteria in large filtered-water reservoirs. This is still, however, one of those points which can never be definitely settled so far as moderately polluted waters are concerned. It is, however, very desirable to have the storage sufficient to balance the hourly fluctuations in consumption, and for American conditions this will require a reservoir capable of holding about 30 per cent. of the average daily draft,

presuming that the filters have sufficient area to deliver the maximum daily draft without exceeding the maximum rate of filtration established for them. This is about a seven hours' supply at the average daily rate; Professor Burton recommends about ten hours' supply as a minimum, in addition to a fire reserve, expressed by the empirical formula:

> Minimum cubic feet of storage for fire reserve should be about 200 times the square root of the number of inhabitants served.

The proper allowance for fire reserve for American conditions must be determined by a special study. Should there be a large distributing reservoir in the system it should be taken into account in the designing of the filtered-water reservoir, and the combined capacity of the two should be sufficient, at least, to balance the daily and hourly fluctuations of draft and provide the proper reserve for fires and for accidents to the machinery. See also page 108. Frequently, as in the Berlin and Hamburg plants, other reservoirs are provided in the system, and the capacity of the small reservoir at the works need not then be over from 5 to 7 per cent. of the daily mean supply, and the rest of the storage may be provided for at other points.

The most economical shape for a rectangular covered reservoir, if not subdivided, is the square. If divided into two basins by a partition wall costing about as much per foot run as the side-walls, the length of the short side of each basin should be three fourths the length of the long side. For any

other number of basins the formulas given on pages 115 and 117 may be used.

Depth.—Since the relative amounts and costs of excavation and masonry vary with the depth of a reservoir, it is evident that there is one depth which will be less expensive than any other. For unroofed square reservoirs, without partitions, the most desirable depth can be found approximately, according to Prof. Frühling,* by the following formula:

$$d=\sqrt[5]{\frac{Q(r+s+w)^2}{36m^2}}.$$

If divided by a partition wall into two basins:

$$d=\sqrt[5]{\frac{Q(r+s+w)^2}{54m^2}}.$$

In the latter equation the length of the sides of each basin are as 3 to 4.

In these formulas:

Q = capacity of reservoir to high-water line in cubic feet.

d = depth of water in feet.

r = cost of excavation in cents per square foot of area of finished reservoir.

s = cost of floor of reservoir in cents per square foot.

w = cost in cents per square foot of the land upon which the reservoir is built.

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* Handbuch der Ingenieurwissenschaften, III–I–II.

$m =$ a factor depending upon local conditions, being the cost per cubic foot of masonry multiplied by the percentage of thickness of masonry surrounding walls to their height.

These formulas will also serve for rectangular covered reservoirs if the value of m is increased to correspond with the additional masonry in the piers, and if s is increased by the additional cost of the arches and earth covering over them and the piers supporting the roof. A few trials will quickly determine the economical depth.

If the reservoir is covered with arches carried on piers its bottom area must be increased to compensate for their submerged volume.

In case the reservoir is at a considerable elevation above the works the economical depth is influenced by the cost of pumping. If the bottom of the reservoir is established at the proper height to give the required pressure, the water-surface level will fluctuate with the draft, and it is, therefore, apparent that the depth will affect the cost of pumping. The economical depth may be found by approximation from the formula,*

$$\sqrt{d^5} = \frac{Q(r + s + w)}{6m} - \frac{qd^2k}{12m\sqrt{Q}},$$

for an unroofed square reservoir, and

$$\sqrt{d^5} = \frac{Q(r + s + w)}{m\sqrt{54}} - \frac{qd^2k}{:13m\sqrt{Q}}.$$

for an unroofed reservoir with one partition wall.

* Frühling, Handbuch der Ingenieurwissenschaften, III–I–II.

Q = capacity of reservoir in cubic meters.
d = depth of water in meters.
r = cost of excavation per sq. meter.
s = cost of floor of reservoir per sq. meter.
w = cost of land per sq. meter.
m = a factor depending on local conditions, being the cost per cubic meter of masonry multiplied by the percentage of thickness of masonry surrounding walls to their height.
k = the capitalized cost of both operating expenses and fixed charges per kilogram of water raised one meter high per second, and
q = the average quantity of water to be pumped in litres per second.

The value of d can be most easily found by successive approximations.

From an analysis of the formula it is easily seen that the influence of the depth upon the total cost, considering also the cost of pumping, will be greater the smaller the capacity of the reservoir relative to the daily delivery of the pumps.

It frequently will occur that the shape of the ground available, the price of the land, the depth of the ground-water below the surface of the ground or the character of the subsoil will determine the size and depth of the reservoir, and the theoretical considerations for greatest economy will have to be modified to suit such conditions.

Bottoms.—To secure a water-tight reservoir requires the greatest care in workmanship in all particulars, and on such works only experienced and

competent workmen should be employed. Water-tight masonry, in the true sense of the word, does not exist, because all ordinary stones, mortars and bricks are permeable, to greater or lesser degrees, particularly under high pressures. A careful handling of the materials will, however, reduce this leakage to very small limits under the low heads usual in reservoirs of this class. The modern practice in the construction of masonry reservoirs tends towards concrete, brick and stone structures plastered inside with cement mortar to secure tightness. The tendency is also to dispense with clay-puddle, although its use is quite common in American, English and some of the continental works, notably Hamburg and Warsaw.

It seems to be the general concensus of opinion, however, that for filtered-water reservoirs built upon sites where danger of contamination exists from ground-water a bed of carefully placed and compactly puddled clay is essential. The clay should preferably be mixed with about an equal volume of gravel or gravel and sand. In masonry of this class the stones should be rather small, sound, clean and have rough surfaces. The mortar should be made from a good strong Portland cement and sharp clean sand. All the bricks and stones should be moist when laid so as not to absorb the water from the mortar. They should be laid quickly, and all the joints should be filled completely. Concrete and range-rubble work are also used extensively, but in all these forms the

ability to resist leakage is derived largely by a plastering coat, on the walls and bottom, of Portland cement mortar from one eighth to three sixteenths of an inch thick rubbed down with a wooden float. The mortar should be mixed in the proportion of about one part of cement to two parts of sand, and a small quantity of thoroughly slaked lime may be added to increase the tightness and make it easier to smooth down. Finally, the walls should receive a wash of neat cement, applied with a broom or with a trowel, in the latter case being polished with a felt float. Polishing with a metal float is not satisfactory, because the surface is apt to check in fine cracks when the cement has set. Upon the bottom a very thin layer of dry cement should be strewn by experienced men. This will adhere to the damp concrete bottom and make a very smooth hard surface, from which algæ and other low plant-life and deposits may be readily washed.

The bottoms of the basins sometimes require especial care in construction to make them water-tight. The site chosen for the filtered-water reservoir for the Hamburg Water-works is adjacent to the old settling basins at Rothenburgsort, which were in service at the time the reservoir was being built. The soil was very unstable and great precautions were necessary to prevent the formation of springs by the excavation for the new reservoir. The excavation when finished and leveled off was lined with an 8-inch layer of well-compacted clay, upon which the concrete bottom of the reservoir was

laid. In the mass of the concrete, which was 20 inches thick, was embedded a system of angle-irons crossing at right angles, and fastened to a heavy channel-iron running around the exterior edge. Upon this concrete floor the walls and piers are built which carry the roof.

Walls.—In reservoirs built on a more or less compressible foundation, like clay-puddle, the side-walls and pillars should be carried up to a considerable height, in order that the settlement may cease before laying the floor so that there may be no future settlement due to this cause.

Where iron pipes pass through the masonry there is always difficulty in making tight joints. If there is danger of settlement of the walls the pipes should be carried through in openings considerably larger than they require, and all the settlement should be allowed to take place before the hole is filled up. To prevent leakage along the pipes a series of collars should be made on the part passing through the wall, and the hole should then be filled in with good, strong concrete, care being taken that the mortar is in perfect contact with the iron work and the masonry in all places.

The side-walls of covered reservoirs are usually straight, designed as retaining walls to resist the external pressure of the earth, with buttresses opposite the points from which arches spring, as in the reservoir at Geneva, Switzerland. In some of the German and Italian reservoirs, however, they are made of an economical section designed to take the thrust

of the arch in a curved line to the bottom of the foundation, as at Wiesbaden. Mr. Wm. H. Lindley, C.E., of Frankfort-on-the-Main, uses frequently a comparatively thin wall arched between heavy buttresses spaced several feet apart in the length of the wall. The weight and load of each pier supporting the roof is distributed over a large area of the floor by inverted arches turned between the bottoms of the piers.

Covers.—Filtered-water reservoirs should nearly always be roofed over to exclude light, to protect them from contamination and from the influence of temperature changes. The roofing may be done in a variety of ways. Groined, domical or cylindrical arches may be used for covering, as explained in chapter IV., or combination roofs of steel and concrete, or steel and brickwork may be employed advantageously. The roofs of filtered-water reservoirs should be made water-tight by a coating of asphalt and asbestic paper in two or three courses, with properly broken joints, and the water percolating down to the top should be carried away in a system of drain pipes. For this reason cylindrical arches are more suitable for reservoir-roofs than groined or domical structures, as the drains for the roof may be laid in the valleys between the vaults. Light trussed roofs of iron or wood, covered with tin, slates or asphalt, may sometimes be sufficient where cheapness in first cost is a desideratum. Roofs of this kind are satisfactory for excluding light and affording plenty of ventilation in summer, but offer no consider-

able protection against prolonged severe cold, unless means are provided for heating the space above the water, by which the cost will be increased considerably. The Koenigsberg filters are covered with a trussed roof.

There may be, occasionally, situations where, owing to the constituents of the water, it would be unsuited, after filtration, to support vegetal growths. With such waters, possibly, covering of the filtered-water reservoirs would not be essential. This question is one that is occupying considerable attention on the part of biologists. In some cases, where proper conditions exist, the omission of covers over the reservoirs may assist in saving a community considerable expense. It is a point well worth examination.

If, instead of using piers or columns to support the roof, solid thin partition walls be built up from the bottom, dividing the reservoir into narrow parallel channels, the spaces being spanned with barrel arches, and each wall pierced with an opening at alternate ends, the water will be kept in constant motion and stagnation will be prevented.

Ventilation.—There should be a number of ventilation shafts placed over the reservoir to balance the air-pressures due to fluctuating water levels. The ventilators should be so constructed as to admit air, but exclude mice, toads, insects and flies. Light-shafts covered with heavy wire-glass should be built at convenient points to permit the cleaning of the

reservoir. They should be covered with an opaque lid of some sort when the reservoir is not in cleaning.

A covering of earth two or three feet thick should be spread over the top of the masonry cover to prevent injury of the structure by frost and to prevent the water from freezing.

It is desirable that the outlet for water from the reservoir should be at the opposite end of the reservoir from the inlet, in order that all the water may circulate through the reservoir to avoid stagnation in parts distant from the outlet. The necessary valves should also be provided for draining the reservoir and the different compartments, independently, in case repairs should be necessary or cleaning desirable. Capacious over-flow pipes should likewise be provided. Under the drain pipe there should be a sump, into which all sediment and dirt may be pushed when cleaning. A large manhole over the sump will be necessary for the removal of this matter, in buckets, by the workmen.

Frequently it will also be desirable to have an automatic depth-recording apparatus, when the reservoir is at some distance from the works, which will indicate the state of the water in the reservoir upon a chart in the office of the works, or the pump-house, if desirable.

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